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FOURTH QUARTERLY REPORT

PRESSURE MEASURING SYSTEMS FOR CLOSED CYCLE LIQUID METAL FACILITIES

Anthony J. Cassano

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Consolidated Controls Corporation

Bethel, Connecticut

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FOREWORD

The major contributors to this development program are Mr. R. Engdahl, Project Manager, Mr. Anthony Cassano, Mr. David Mends and Mr. Philip Tubman.

ABSTRACT

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Continuing development of a pressure transducer system for liquid metal applications is described. During the report period, fabrication and assembly of the test pressure capsules (C-129Y, FS-85, T-222 and W-25Re alloys) were completed and the deflection tests utilizing an optical measurement technique were concluded. A preliminary design has been developed for a complete transducer instrument incorporating a thermionic diode sensor. Tests are in progress to evaluate the metal-ceramic joining techniques planned for use in the transducer design. A complete set of single convolution pressure capsules and electrical terminals has been prepared. These test units are being charged with liquid potassium. Construction has started on the compatibility test facility. Author

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1.0 Introduction

The objective of this program is to develop pressure transducer equipment compatible with advanced closed cycle power systems. These systems utilize liquid metals such as mercury, sodium, potassium and other alkali metals as working and heat transfer media at elevated temperatures. Accurate pressure measurements in the high temperature liquid, vapor, and two phase streams are required for research, design and control purposes. In addition, space flight requires lightweight systems capable of enduring long periods of unattended operation.

Liquid metal pressure measurements at elevated temperatures pose many design problems demanding the best from available materials. To establish a firm design base for the transducer equipment, four materials and two transducer systems have been chosen for evaluation. The selected material and transduction system will be developed for use as either ground or flight hardware.

2.0 Summary

Fabrication and assembly of the test pressure capsules (C-129Y, FS-85, T-222 and W-25Re alloys) were completed and the deflection tests utilizing an optical measurement technique were concluded. The test results are presented along with a discussion of the test procedures employed.

The test procedures for the pressure capsules were designed to determine

1. the transducer pressure-deflection calibration at temperatures from room temperature to 1800°F,
2. the influence of 200 percent overpressure at 1800°F on full scale deflection and zero repeatability,
3. the repeatability at 100 percent applied pressure and 1800°F, and
4. the influence of the deflection magnitude on reproducibility.

For this work some pressure cycling and overpressuring were done before the final test for repeatability at 1800°F for each test capsule. However, the pressure cycling was intentionally limited so that the influence

of pressure cycling could be observed. The temperature-deflection tests show that the pressure capsules had not been completely stabilized prior to test. Future testing will be performed only after a more extended pressure cycling test program.

The best performance was obtained with the W-25Re capsule using 0.002 inch full scale deflection. After six hours at 100 percent pressure and 1800°F, the full scale deflection had changed by +3.9 percent, the zero had moved +2.3 percent, and upon repressurizing, the full scale deflection increase repeated at +4.2 percent.

Tests were continued on the thermionic diode sensor employing 0.001 inch active collector travel. Output current-travel characteristics were obtained with maximum deviations from linearity of 1.5 percent full scale.

The thermionic diode sensor was selected for the final design and incorporated in a preliminary arrangement for a complete transducer instrument. A pressure-temperature lift test is in progress on a sample metal-ceramic seal planned for use in the transducer design. Present test parameters for the metal-ceramic seal are 1000 psia and 1800°F. No electrical or mechanical failure has been noticed during the hours of test.

A complete set of single convolution pressure capsules and electrical terminals has been prepared for the potassium compatibility test program. The test units are being charged with liquid potassium. Design and construction of a compatibility test facility is underway.

3.0 Pressure Capsule

During the report period, fabrication and assembly of the test pressure capsules were completed and the deflection tests utilizing an optical measurement technique were concluded.

Analysis of the high temperature data with limited pressure and temperature cycling yields the following results.

1. Capsule hysteresis at temperatures up to 1800°F is negligible for small full scale deflections.
2. The increase in full scale deflection with temperature generally follows the predicted change based on literature values of Young's modulus.
3. The zero shift resulting from 200 percent overpressure for 2 hours at 1800°F was found to be acceptable for the FS-85, T-222, and W-25Re capsules.
4. The zero shift data taken during the final time test period showed that the W-25Re capsule was the most stable.
5. Additional pressure cycling at 1800°F will be required before the evaluation of the test capsules can be completed.

3.1 Test Procedure

The deflection measurements using optical means has given results of pressure capsule behavior. The information included

1. capsule pressure-deflection characteristics as functions of temperature,
2. capsule creep characteristics when subjected to full-scale pressurization for periods up to 22 hours at 1800°F and
3. capsule overpressure characteristics for 2 hour periods at 1800°F.

The procedure developed to obtain this information involves the following steps:

1. Perform pressure-deflection calibration runs at room temperature, 500, 1000, 1200, 1400, 1600 and 1800°F.
2. Maintain full scale deflection and 1800°F for a period of 20 hours. Measure the full scale and zero pressure separations every 6 to 7 hours. Calculate the full scale deflections and zero shifts.

3. Perform pressure-deflection calibration runs at 500, 1400 and 1800°F.
4. Apply overpressure to 200 percent maximum deflection (or until the diaphragm is close to the mechanical stop) at 1800°F for a 2 hour period. Measure the full scale and zero pressure separations every hour. Calculate the full scale deflections and zero shifts.
5. Perform pressure-deflection calibration runs at 500, 1400 and 1800°F.
6. Maintain full scale deflection and 1800°F for a 6 hour period. Measure the full scale and zero pressure separations every 3 hours. Calculate the full scale deflections and zero shifts.

The term "zero pressure separation" refers to the distance between two markings, one on the capsule projection tip and the other on the capsule deflection yoke (see Figure 26, Reference 3), under conditions of zero psia capsule pressurization. When full-scale pressure is applied to the capsule, the distance between the same two markings is termed the "full scale separation". The "full scale deflection" is obtained by subtracting the full scale separation from the zero pressure separation. "Zero shift" refers to a change in value of the zero pressure separation.

A chronological representation of the test procedure is shown in Figure 1. Points at which full scale and zero pressure separations are measured along with total operation time and time at 1800°F are indicated. Variables in the procedure include the length of time of the sustained full scale pressure test (shown as 22 hours in Figure 1) and the overpressurization value used. The zero pressure separation reading after the first 6 to 7 hours of the sustained pressure test was not normally taken. Each pressure-deflection calibration test required about 2 hours; the pressure capsule experienced about 56 hours of total operation, 36 hours of which were at 1800°F. The capsule underwent a total of 13 full-scale pressure cycling tests at various ambient temperatures. In addition, three 1800°F time tests were included in the test procedure; 22 hours at 100 percent pressure, 2 hours at 200 percent overpressure, and a final 6 hour test at 100 percent pressure.

The instrumentation has been fully discussed in the past quarterly reports (References 1, 2, 3) and employs a 40X magnification binocular microscope through which photographs are taken on glass metallographic plates. Separation readings are then taken from the developed plates using a shadowgraph instrument. This system has exhibited accuracies better than ±20 microinches (±2 percent referred to a full scale deflection of 0.001 inch).

3.2 Test Results

A complete set of pressure-deflection-temperature tests have been conducted on the four candidate pressure diaphragm materials (C-129Y, FS-85, T-222, W-25Re). To investigate fully the high temperature stress effects, full scale deflection values were selected which are realistic for transducer operation. In addition, both single and double convolution capsules were included in the test program.

A complete listing of the test capsules, the applicable full scale deflection parameters and the chronological order in which the deflection tests were performed is given in Table 1. The maximum deflection values of 0.0006 and 0.001 inch for single convolution capsules correspond to values of 0.001 and 0.0017 inch respectively for double convolution capsules (see Appendix B).

Figures 2 through 76 present the complete series of pressure-deflection-temperature data as scheduled in Figure 1 for time increments 0 to 14 (time scale a).

TABLE 1

PRESSURE CAPSULE LINEARITY-HYSTERESIS ERRORS

Capsule Material	Number of Convolutions	Nominal Room Temp. Full Scale Deflection (inch)	Start of Test	Linearity-Hysteresis (a) Percent of Full Scale Deflection				Allowable Operating Temperature
				1000°F	1400°F	1600°F	1800°F	
C-129Y	1	0.0006	1/21/65	5.5(b)	5.5	4.8	4.7	1800°F
C-129Y	1	0.001	1/6/65	5.0	6.5	6.3	12	1600°F
C-129Y	2	0.002	11/30/64	6.4	4.7(b)	11	13	1400°F
FS-85	2	0.001	2/3/65	4.7	4.2	4.0	3.4	1800°F
FS-85	2	0.002	12/16/64	2.7	2.8	3.4	6.2	1600°F
FS-85	2	0.004	10/27/64	0.9	3.8	NM	10	1400°F
T-222	1	0.0006	2/5/65	8.7(b)	5.8	7.4	5.5(b)	1800°F
T-222	1	0.001	1/28/65	2.5	4.2	4.2	6.3	1600°F
W-25Re	2	0.001	1/12/65	8.3	9.3	8.3	9.0	1800°F
W-25Re	2	0.002	11/18/64	5.9	6.8	3.2	6.7	1800°F
W-25Re	2	0.004	12/10/64	2.6(b)	2.2	5.0	3.6(b)	1800°F

NM Not Measured

(a) The term linearity-hysteresis is used in this report to mean the error in percent of full scale deflection between the individual data points and the reference straight line.

(b) Identifies error values which have been calculated by omitting data points which appeared to be grossly different than the general data pattern. It is believed that this method provides the most representative description of actual capsule performance.

Information of interest which can be derived from these data as a function of operating temperature include linearity, hysteresis, zero shift and Young's modulus.

A straight line has been drawn close to the experimental points of each set of capsule data plots (Figures 2 to 76) to assist in the evaluation of the capsule linearity and hysteresis. Using the line as drawn on each figure, it will be noted that the linearity error is not apparent but as the operating temperature increases the hysteresis errors become more pronounced. The inability to discern the linearity error demonstrates that the capsule linearity error is smaller than the optical measurement system error. To simplify the problem of data evaluation, the linearity and hysteresis errors have been combined into a single term called "linearity-hysteresis error".

The linearity-hysteresis error is established by determining the deviation of the individual data points from the straight line and calculating the error in percent of full scale deflection at the operating temperature.

The maximum error value for each capsule test has been tabulated in Table 1. The test data contains some points which are grossly different from the general hysteresis pattern for a particular test. In these instances, the maximum values representative of the data pattern were selected for use in Table 1. There are six values of this type identified in the table by note (b).

The purpose of Table 1 is to make possible the selection of the deflection limit for a particular candidate alloy when used as a pressure capsule. Table 1 also lists this deflection limit in terms of allowable operating temperature for each capsule tested. The selection is based on the last temperature test condition for which there is no noticeable increase in the linearity-hysteresis error. Using the C-129Y capsules as an example, it will be noted that for a single convolution capsule with 0.0006 inch full scale deflection there is no appreciable increase in the linearity-hysteresis error from 1000°F to 1800°F. When the full scale deflection is increased to 0.001 inch, the linearity-hysteresis error rises sharply between 1600°F and 1800°F.

For the C-129Y double convolution capsule with 0.002 inch full scale deflection, the change occurs between 1400°F and 1600°F. This information can be used to compute the maximum allowable operating stress for new capsule designs to assure that linearity-hysteresis will be small at the desired operating temperature. Each material has been operated at a stress level low enough to minimize the linearity-hysteresis error at 1800°F. The W-25Re capsule has shown the best range of useful operating conditions.

Tables 2, 3, 4 and 5 present the zero shift and full scale data scheduled by Figure 1 (see time scale b) at nominal times 2 to 24, 26 to 28, and 30 to 36. All data for this portion of the evaluation are at 1800°F. The purpose of the first time period (2 to 24 hours) was to provide a limited amount of pressure cycling and operating time at temperature to stabilize the performance of the pressure capsule before subjecting it to the 200 percent overpressure test (26 to 28) and the final time test for creep at full pressure and temperature (30 to 36).

TABLE 2
C-129Y PRESSURE CAPSULE DEFLECTION VARIATIONS
(PERCENT OF FULL SCALE AT 1800°F) WITH TIME AT 1800°F

Number of Convolutions	1			1			2		
Nominal Room Temp. Full Scale Deflection (inch)	0.0006			0.001			0.002		
	Test Hours (b)	Zero Press. ±3.3%(a)	Full Scale ±3.3%(a)	Test Hours (b)	Zero Press. ±1.3%(a)	Full Scale ±1.3%(a)	Test Hours (b)	Zero Press. ±0.8%(a)	Full Scale ±0.8%(a)
First Time Test	(2-9)	NM	29.0	(2-9)	135	133(c) 127(c)	(2-8)	142	147(c) 128(c)
	(2-17)	46.1	50.0	(2-15)	NM	NM	(2-16)	207	100(c) 196(c)
	(2-24)	NM	64.7(c) 63.3(c)	(2-24)	240	238(c) 228(c)	(2-21)	NM	231
200% Overpressure Test	(26-27)	15.2	23.2(c) 31.2(c)	(26-27)	-19.8	-13.3(c) -40.6(c)	(23-24)	NM	NM
	(26-28)	19.4	35.1	(26-28)	-79.0	-51.6	(23-25)	NM	NM
Final Time Test	(30-33)	26.4	54.6(c) 42.5(c)	(30-33)	NM	NM	(27-30)	NM	NM
	(30-36)	40.0	56.3(c) 56.8(c)	(30-36)	27.4	37.8	(27-33)	53.9	40.1

(a) ±20 microinches measurement accuracy referred to max. full scale deflection at 1800°F
(b) Refers to operating hours at 1800°F (scale b of Figure 1) between which variations took place
(c) Capsule brought to zero pressure between readings
NM Not measured

TABLE 3
FS-85 PRESSURE CAPSULE DEFLECTION VARIATIONS (PERCENT OF FULL SCALE AT 1800°F) WITH TIME AT 1800°F

Number of Convolutions	2			2		
Nominal Room Temp. Full Scale Deflection (inch)	0.001			0.002		
	Test Hours (b)	Zero Press.	Full Scale	Test Hours (b)	Zero Press.	Full Scale
		±1.7%(a)			±0.7%(a)	
First Time Test	(2-9)	NM	24.2	(2-8)	64.9	59.9(c) 60.5(c)
	(2-18)	22.4	27.2(c) 17.9(c)	(2-14)	87.7	83.9(c) 77.4(c)
	(2-24)	22.2	25.8(c) 19.8(c)	(2-23)	110	90.1
200% Overpressure Test	(26-27)	3.4	0.4(c) 5.7(c)	(25-26)	14.3	9.0
	(26-28)	-3.2	12.3(c) 1.8(c)	(25-27)	NM	8.3
Final Time Test	(30-33)	12.0	21.1(c) 13.8(c)	(29-32)	NM	6.0
	(30-36)	12.8	21.4(c) 11.6(c)	(29-35)	24.8	7.1

(a) ±20 microinches measurement accuracy referred to max. full scale deflection at 1800°F
(b) Refers to operating hours at 1800°F (scale b of Figure 1) between which variations took place
(c) Capsule brought to zero pressure between readings
NM Not measured

TABLE 4

T-222 PRESSURE CAPSULE DEFLECTION VARIATIONS (PERCENT OF FULL SCALE AT 1800°F) WITH TIME AT 1800°F

Number of Convolutions	1			1		
Nominal Room Temp. Full Scale Deflection (inch)	0.0006			0.001		
	Test Hours (b)	Zero Press.	Full Scale	Test Hours (b)	Zero Press.	Full Scale
		±3.1%(a)			±1.6%(a)	
First Time Test	(2-9)	NM	-8.7	(2-8)	NM	30.2
	(2-18)	-1.3	6.7(c) -4.7(c)	(2-17)	26.2	25.1(c) 26.5(c)
	(2-24)	-22.3	-11.1(c) -24.0(c)	(2-22)	32.4	25.5(c) 26.3(c)
200% Overpressure Test	(26-27)	7.1	9.9(c) 8.1(c)	(24-25)	2.9	2.4(c) 4.9(c)
	(26-28)	-3.7	1.1(c) 0.5(c)	(24-26)	3.5	8.0(c) 2.3(c)
Final Time Test	(30-33)	-4.5	-8.5(c) 2.1(c)	(28-31)	-80.0	-71.8(c) -72.8(c)
	(30-36)	25.9	37.8(c) 30.4(c)	(28-34)	-18.5	-12.2

(a) ±20 microinches measurement accuracy referred to max. full scale deflection at 1800°F

(b) Refers to operating hours at 1800°F (scale b of Figure 1) between which variations took place

(c) Capsule brought to zero pressure between readings

NM Not measured

TABLE 5
W-25Re PRESSURE CAPSULE DEFLECTION VARIATIONS (PERCENT OF FULL SCALE AT 1800°F) WITH TIME AT 1800°F

Number of Convolutions	2			2			2		
Nominal Room Temp. Full Scale Deflection (inch)	0.001			0.002			0.004		
	Test Hours (b)	Zero Press. ±1.9%(a)	Full Scale ±1.9%(a)	Test Hours (b)	Zero Press. ±0.8%(a)	Full Scale ±0.8%(a)	Test hours (b)	Zero Press. ±0.5%(a)	Full Scale ±0.5%(a)
First Time Test	(2-9)	NM	-11.1	(2-6)	26.8	-2.2	(2-8)	6.4	18.3(c) 12.5(c)
	(2-18)	-11.4	-18.7(c) -22.3(c)	(2-14)	38.1	9.2(c) 7.2(c)	(2-15)	NM	21.9
	(2-24)	-34.8	-27.2	(2-20)	44.9	20.5(c) 15.1(c)	(2-22)	24.3	32.2(c) 28.7(c)
200% overpressure Test	(27-28)	0.3	7.0(c) 6.8(c)	(22-23)	NM	NM	(24-25)	NM	6.6
	(27-29)	5.3	8.0	(22-24)	NM	NM	(24-27)	5.2	5.9
Final Time Test	(31-34)	12.6	5.3(c) 5.3(c)	(26-29)	NM	NM	(29-32)	NM	NM
	(31-37)	-12.5	-12.1(c) -14.6(c)	(26-32)	2.3	3.9(c) 4.2(c)	(29-35)	14.2	7.7

(a) ±20 microinches measurement accuracy referred to max. full scale deflection at 1800°F
(b) Refers to operating hours at 1800°F (scale b of Figure 1) between which variations took place
(c) Capsule brought to zero pressure between readings
NM Not measured

The double convolution W-25Re capsule operated at 0.002 inch full scale deflection demonstrated repeatability close to that which can be obtained by the optical measuring system (see Table 5). These creep values of less than about 4 percent for a six hour period hold promise that a transducer can be built which will meet the desired long time stability requirements. The data for W-25Re at 0.001 inch full scale deflection seems to indicate that more pressure cycling at temperature is required to stabilize the capsule before the final creep data are taken. The 0.004 inch full scale deflection data show that this deflection generates higher stress than can be allowed for long term stability.

The T-222 pressure capsule data presented in Table 4 show the need for more capsule pressure cycling. This need is exemplified by the negative zero shifts typical for the T-222 capsule. After additional pressure cycling, T-222 may be a useful capsule material.

Table 3 presents the data for the FS-85 capsule. This data and that of Table 2 for C-129Y also show the need for more pressure cycling at temperature. Figures 77 and 78 are presented to show the decrease in hysteresis with increased pressure cycling, which indicates that stabilization is taking place in both the C-129Y and FS-85 capsules during the pressure cycling of the final test (30 to 36 hours). Data taken at consecutive times are identified by letters A through H. The capsule achieves a considerably smaller hysteresis loop with each successive pressure cycle. Thus, after only one cycle the zero shift of the C-129Y capsule is reduced from 26.4 percent to 13.6 percent. Similarly, the full scale deflection creep is reduced from 54.6 percent to 13.8 percent. Comparable results have been measured for the FS-85 capsules. From Figure 78, the values are 21.1 percent full scale deflection creep in the first three hours and 7.6 percent in the second three hours. The zero shift in the first three hours is 12 percent of full scale as compared to only 0.8 percent in the second three hours. It is reasonable to expect that this trend will continue. Future testing will include an extended pressure cycling period before additional data are used to evaluate these two materials for pressure capsule application.

The influence of temperature on full scale deflection is presented in Figures 79 to 82. The measured deflection indicated in percent of full scale deflection is compared in each of the graphs with the predicted percent of full scale deflection based on the change in Young's modulus with temperature. These data seem to show similar trends to that shown by the hysteresis and zero shift data previously discussed. In Figures 79 and 80, the measured values compare closely to the Young's modulus values up to about 1400°F. From Table 1, these same capsules showed a small change in hysteresis at a temperature of 1600°F and a large increase at 1800°F. Figure 81 for the T-222 material indicates that the material has not been fully stabilized as was also shown by the zero shift and full scale deflection-time data in Table 1. Figure 82 indicates a slightly larger change in Young's modulus for the capsule material than that used for the calculated curve.

The data obtained by the optical system have been accurate to approximately one to four percent for full scale deflections of 0.004 to 0.0006 inch respectively. The capsule data presented have shown the need to operate at deflections of 0.0006 to 0.002 inch for which the optical measurement uncertainties are greatest. Also, the lack of continuous readings and the long time interval between taking the photographs and obtaining the deflection readings have created many problems. Since the data obtained have definitely established the basic limitations of each of the candidate materials, it seems advisable to obtain further capsule pressure-deflection data by using the diode sensor for deflection measurements (see Section 4.1).

4.0 Thermionic Diode Sensor

Further tests were conducted on the thermionic diode sensor described in the Third Quarterly Report (Reference 3). The results, shown in Figure 83, were obtained by measuring directly the difference, $(i_a - i_r)$, between the active collector current and the reference collector current, with an active collector travel of 0.001 inch. Linearity was attained within a maximum deviation of ±1.5 percent of full scale.

Figure 84 shows the test circuitry employing precision resistors of 1 ± 0.001 ohm and a digital voltmeter of ±0.1 millivolt accuracy which was used to obtain the calibration curves of Figure 83. The numbered positions of Figure 84 indicate the voltmeter connections. The parameters read using various combinations of these connections are:

Voltmeter Connections	Reading
1 - 2	i_a
1 - 3	i_r
4 - 5	$(i_a + i_r)$
3 - 2	$(i_a - i_r)$
1 - 5	V

4.1 Thermionic Pressure Transducer

A preliminary design has been made for a complete pressure transducer incorporating a double convolution pressure capsule and a thermionic diode sensor. A sketch of the device is shown in Figure 85.

The unit is initially assembled without the protective cover assembly. The encapsulated heater assembly is mounted on posts which are part of the ceramic (Lucalox) base, thereby establishing a fixed emitter-reference collector distance (Figure 86). The emitter-ceramic assembly is then mounted in the housing using the adjusting ring for alignment purposes. After bake-out and emitter activation, the pinch-off tube is closed to maintain vacuum conditions in the thermionic section of the transducer and the adjusting ring can be used for alignment of emitter-active collector distance. To maintain this alignment and distance during operation, the protective cover assembly is provided. The electrical connections are brought out through a second ceramic assembly.

The seal between the adjusting ring and the encapsulated heater-ceramic assembly is of importance. The seal must not only provide a vacuum-tight connection to assure proper operation of the thermionic sensor but it must also provide a back-up liquid metal seal in the event of rupture of the diaphragm.

The main problem areas appear to be:

1. fabrication of the encapsulated heater assembly,
2. development of the metal-ceramic technology necessary to obtain the required seal integrity and
3. establishment of the fabrication procedures necessary to construct the finished transducer.

The first experiment will concentrate on the heater assembly mounted on its ceramic base. The ceramic base will be brazed into a Cb-1Zr support plate and the entire assembly installed in the micrometer head fixture described in the Third Quarterly Report (Reference 3). The fixture allows controlled movement of a simulated active collector. This test will provide experience in construction of the encapsulated heater assembly, mounting of the heater assembly on the ceramic base, and brazing of the ceramic base to the support plates. In addition, it will permit further checking of the linearity and time-temperature stability of the thermionic sensor. The tests will be conducted at various ambient chamber temperatures to ascertain requirements for temperature compensation.

The second experiment will be done with the pressure capsule. One of the capsules tested in the program and reported on in Section 3.2 will be used for this purpose. An active collector will be mounted inside the capsule and the capsule installed in a housing similar to that shown in Figure 85. It appears that introduction of the adjusting ring shown in Figure 85 would be premature at this stage. Since the device will be operated in the Vacuum Test Facility, it will not be necessary to maintain vacuum conditions in the thermionic sensor region by use of the vacuum-tight seal between the adjusting ring and the ceramic base. Therefore, the mounting plate approach employed in the first test device will be used to establish the emitter-active collector distance. It is this second device which will provide the means of obtaining further capsule deflection data.

5.0 Metal-Ceramic Seal Tests

One of the main problems in the development of the thermionic transducer is the development of metal-ceramic seals capable of maintaining vacuum integrity under high-temperature liquid metal attack.

A life test is presently in progress to evaluate the metal-ceramic joining technique planned for use in the transducer. The test sample (Figure 87) contains seals between Lucalox and Nb-1Zr. The Lucalox is metallized with a tungsten-yttria compound and a niobium/nickel/titanium braze material is used. Pressure tests are being performed at 1800°F. The chronology of testing is as follows.

1000 hours at 500 psia, 1800°F
100 hours at 600 psia, 1800°F
100 hours at 700 psia, 1800°F
100 hours at 800 psia, 1800°F
100 hours at 900 psia, 1800°F
1000 hours at 1000 psia, 1800°F (in progress)

No electrical breakdown or mechanical failure (leakage) has been observed. At the conclusion of the present test series, it is planned to conduct similar tests at higher temperature ($\sim$ 2200°F).

6.0 Compatibility Test Program

Four single convolution test capsules of C-129Y, FS-85, T-222 and W-25Re alloy and one test capsule containing four representative electrical terminals have been fabricated and are being charged with liquid potassium. The design configurations are described in the Third Quarterly Report (Reference 3).

Performing individual compatibility tests on each capsule would occupy the Vacuum Test Facility a disproportionate amount of time; therefore, work is progressing on the design of a compatibility test chamber to hold all capsules at the same time. The chamber will have a separate pumping system. In design, the chamber will be similar to the chambers now in operation on the Vacuum Test Facility. Cylindrical strip heaters, with shielding, will be suspended in the chamber and cooling water coils will be used around the outside. Plans call for testing the capsules at 1800°F, which would establish a potassium vapor pressure of about 80 psia. Thermocouples will be used to monitor the temperature of the potassium liquid-vapor interface. The temperature of the test capsules will be monitored by optical pyrometry through the chamber viewing window.

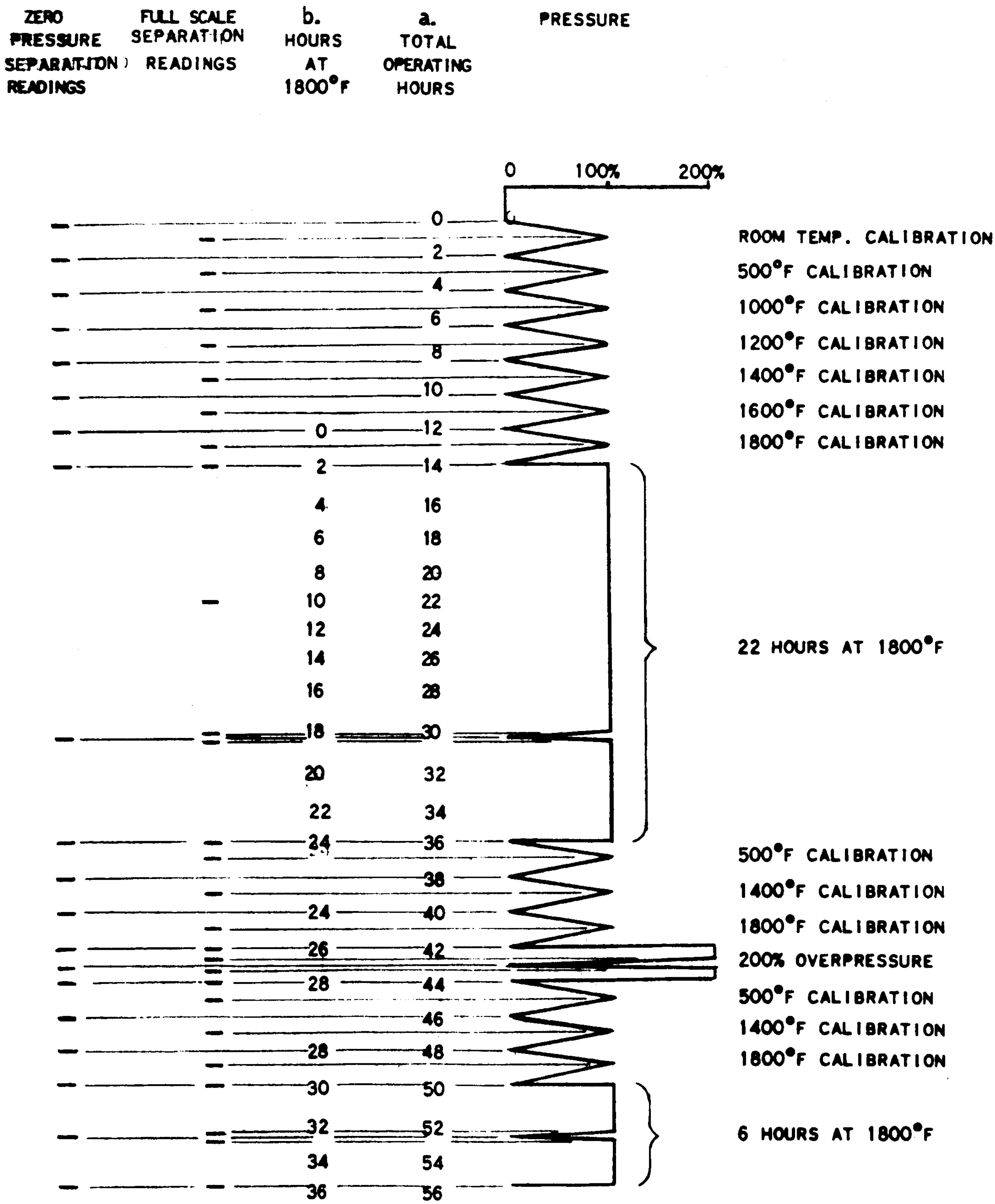

FIGURE 1

DEFLECTION TEST CHRONOLOGY

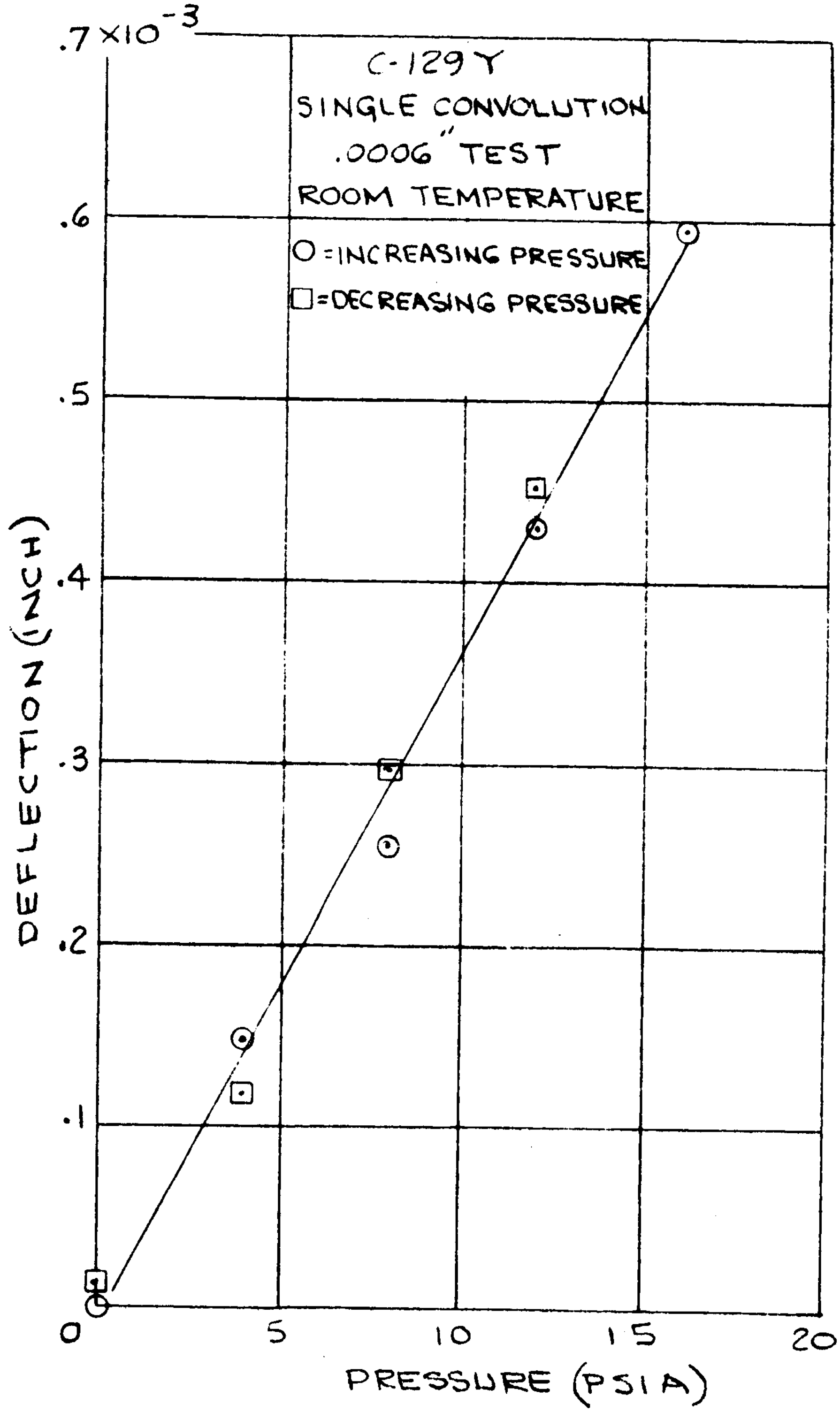

FIGURE 2

C-129Y PRESSURE-DEFLECTION, ROOM TEMPERATURE

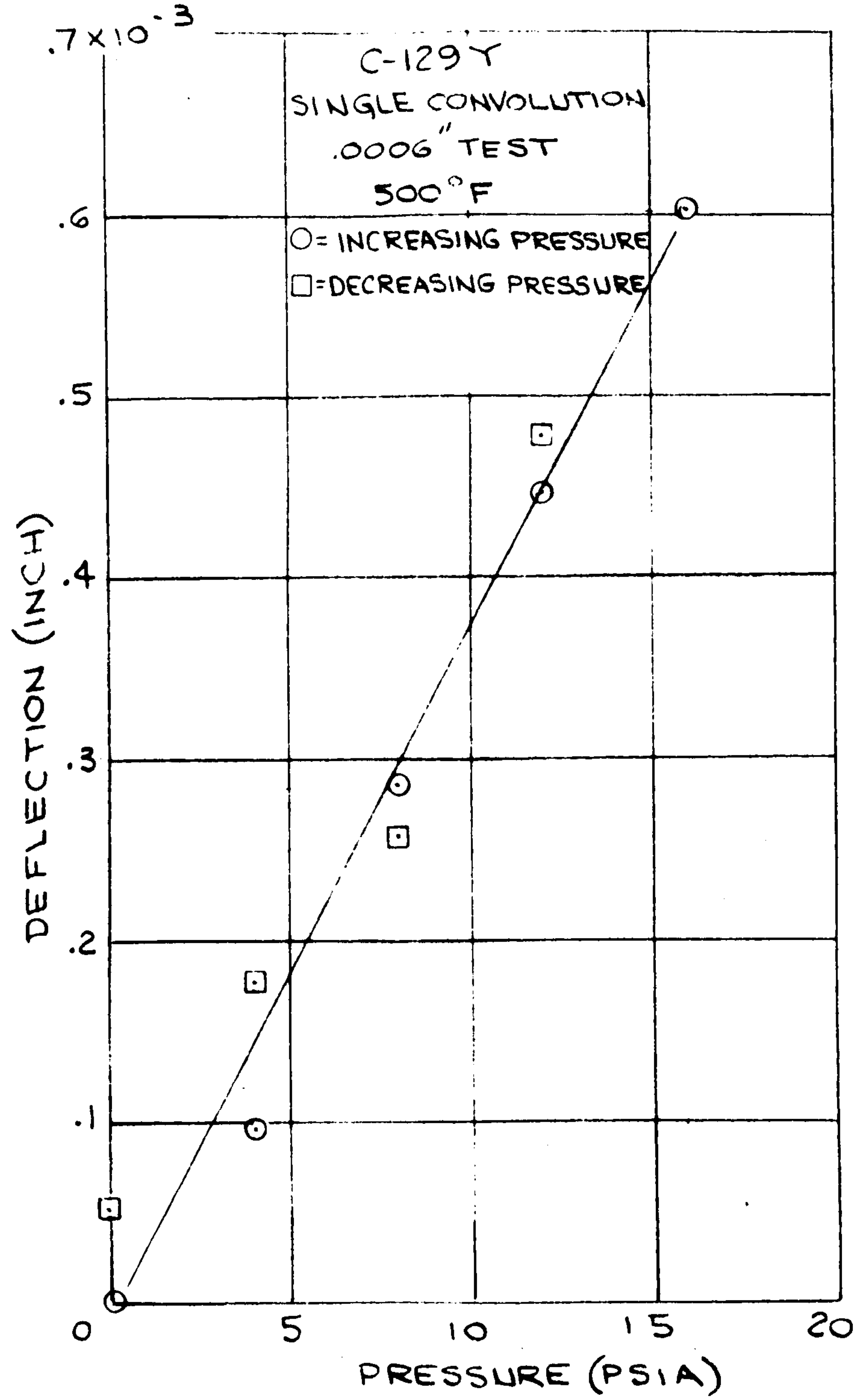

FIGURE 3

C-129Y PRESSURE-DEFLECTION, 500°F

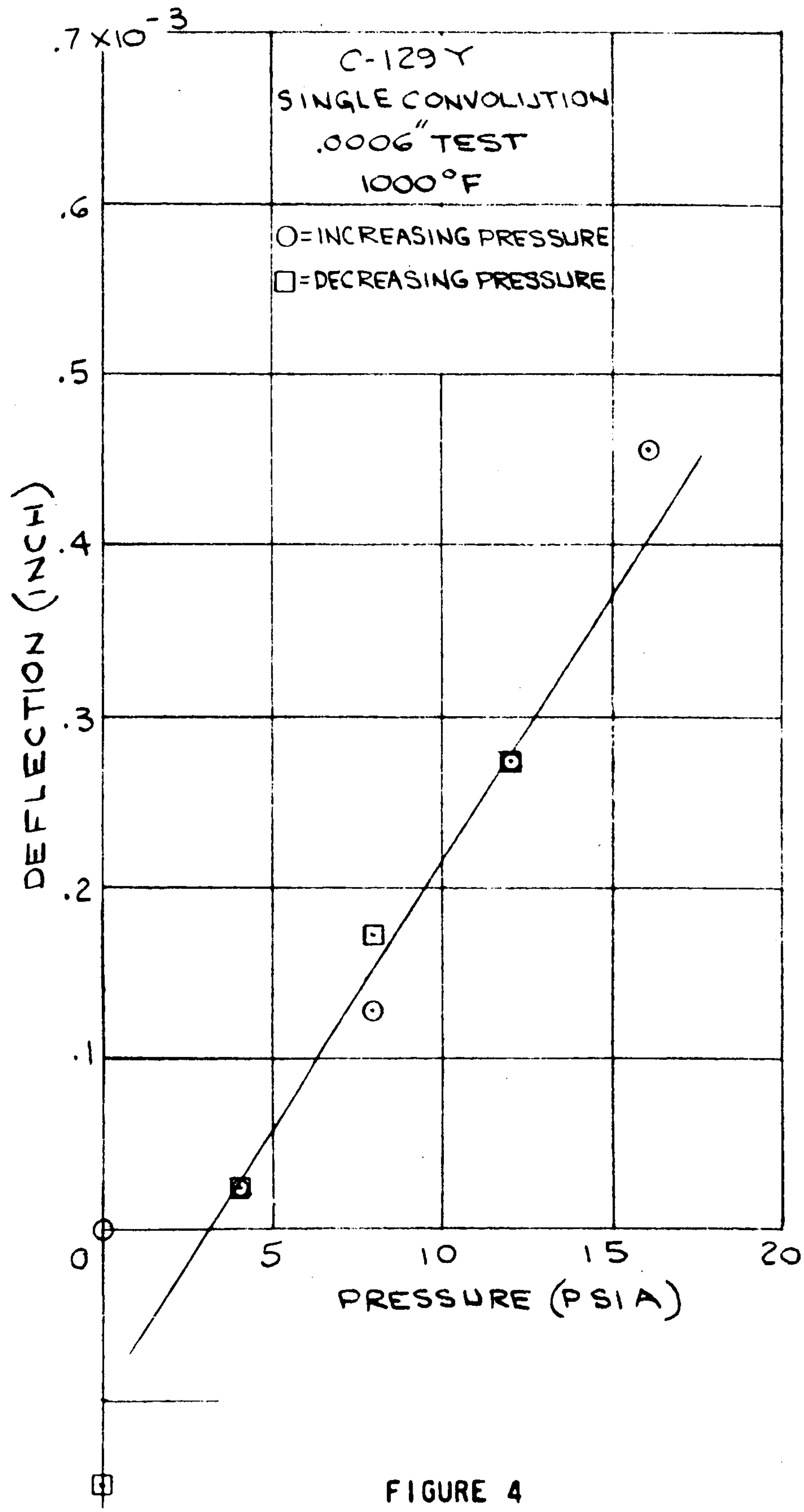

FIGURE 4

C-129Y PRESSURE-DEFLECTION, 1000°F

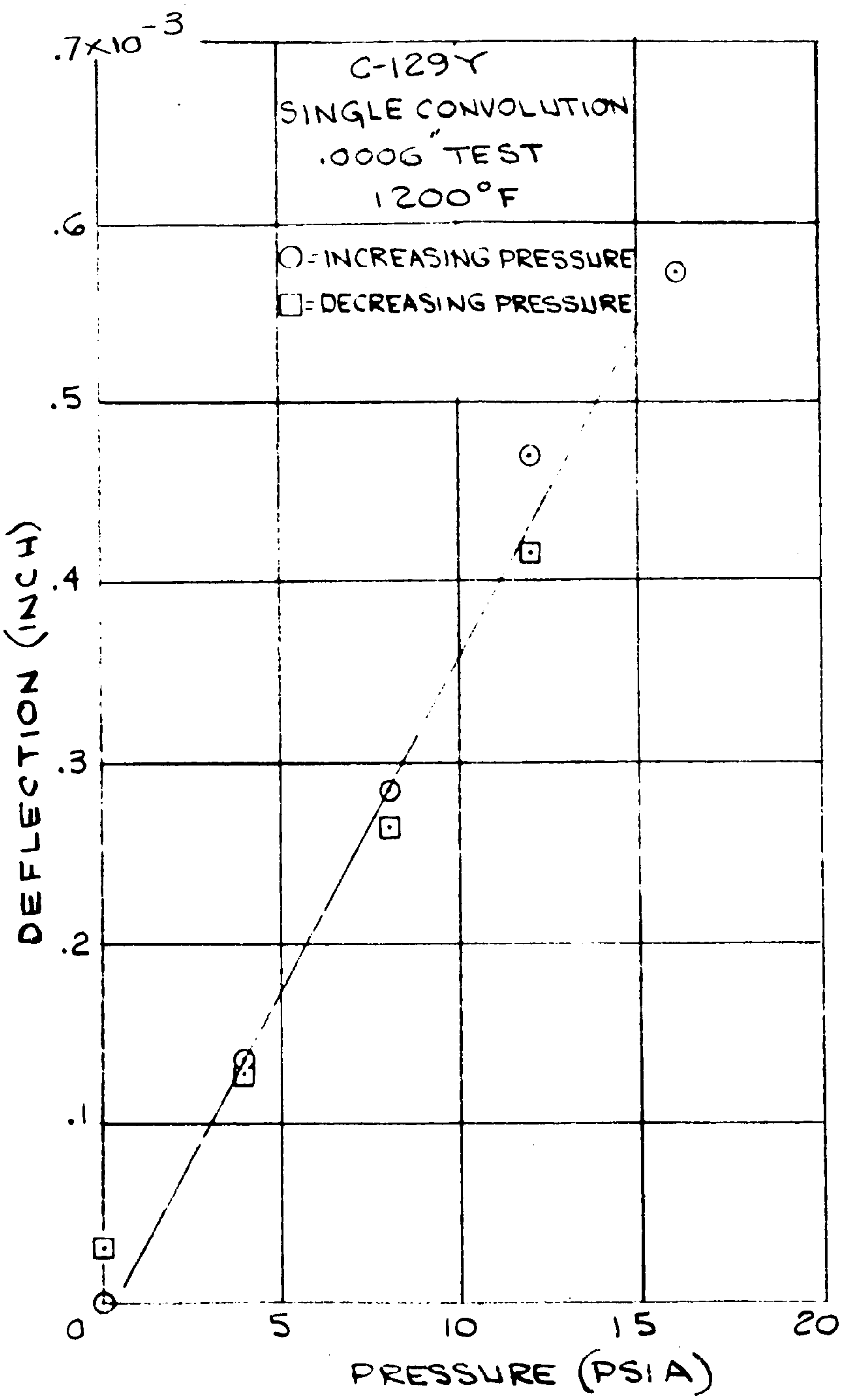

FIGURE 5

C-129Y PRESSURE-DEFLECTION, 1200°F

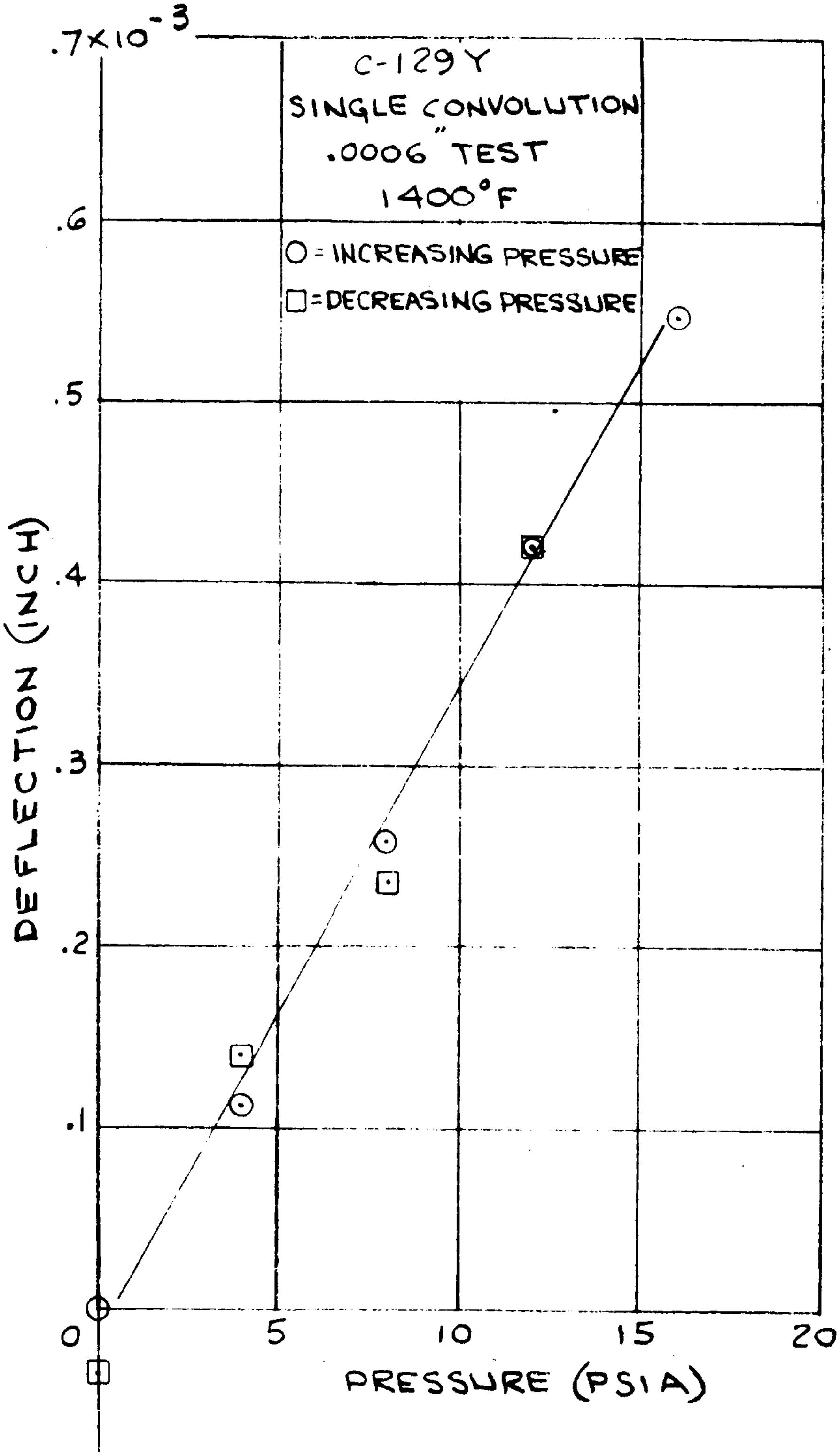

FIGURE 6

C-129Y PRESSURE-DEFLECTION, 1400°F

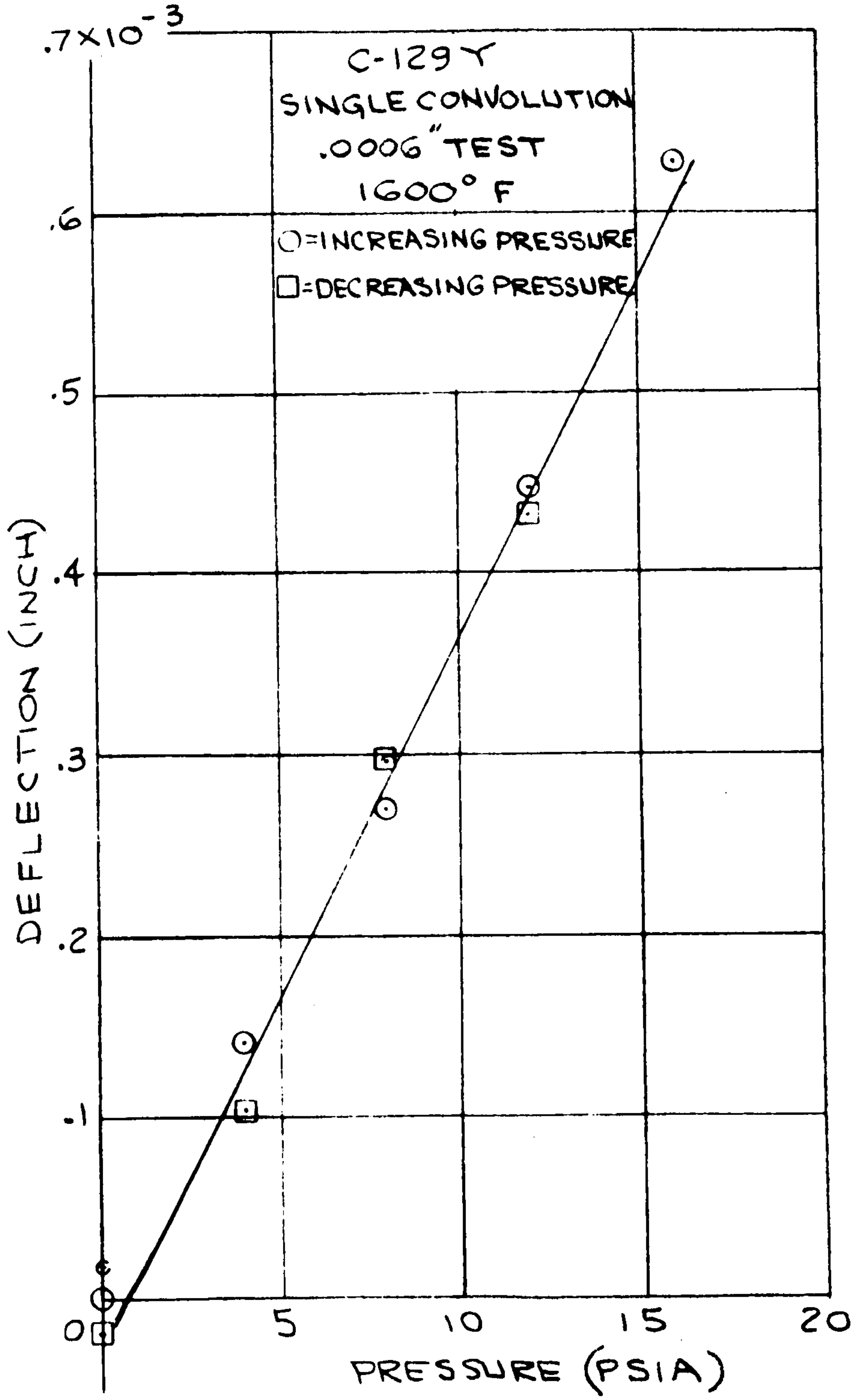

FIGURE 7

C-129 PRESSURE-DEFLECTION, 1600°F

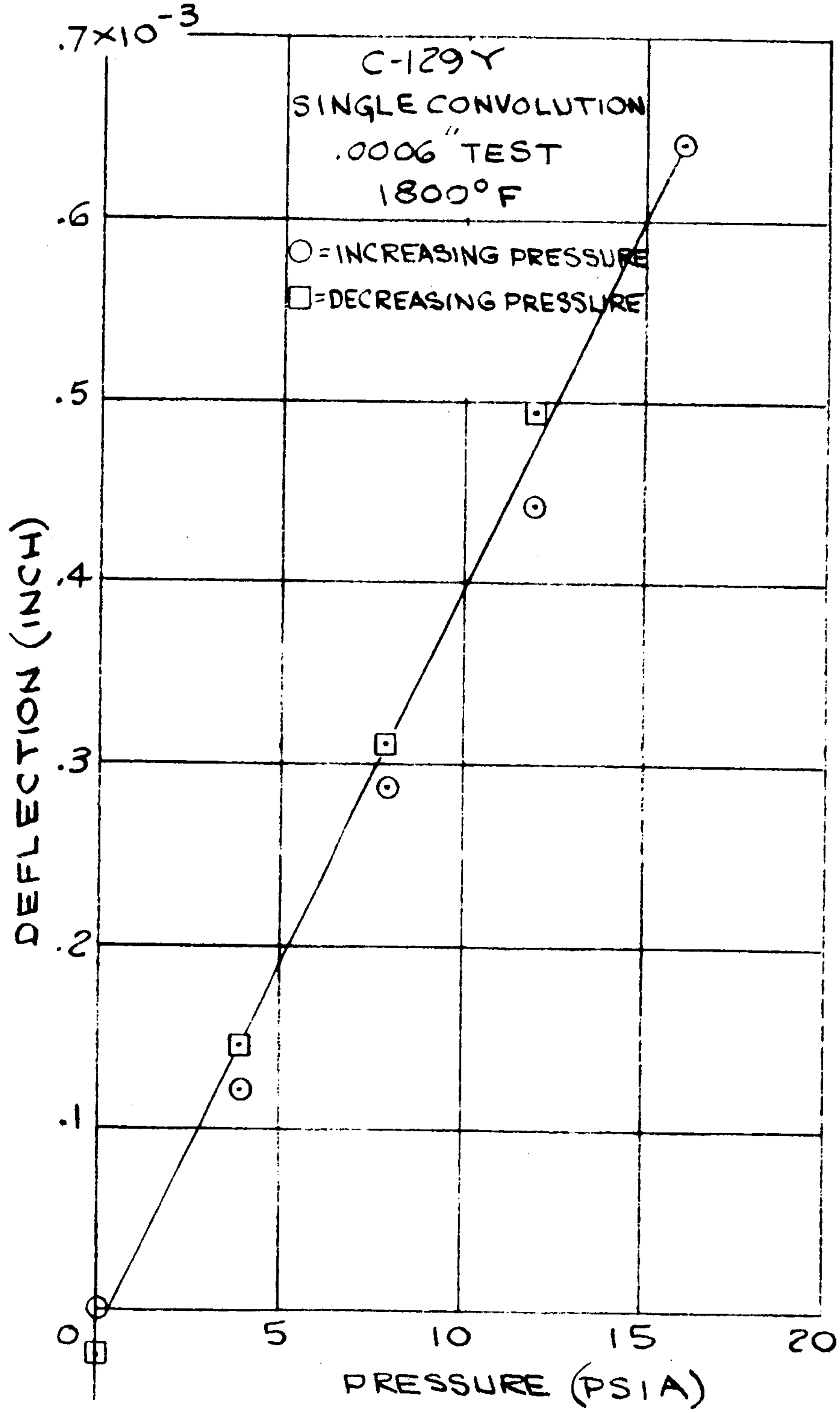

FIGURE 8

C-129Y PRESSURE-DEFLECTION, 1800°F

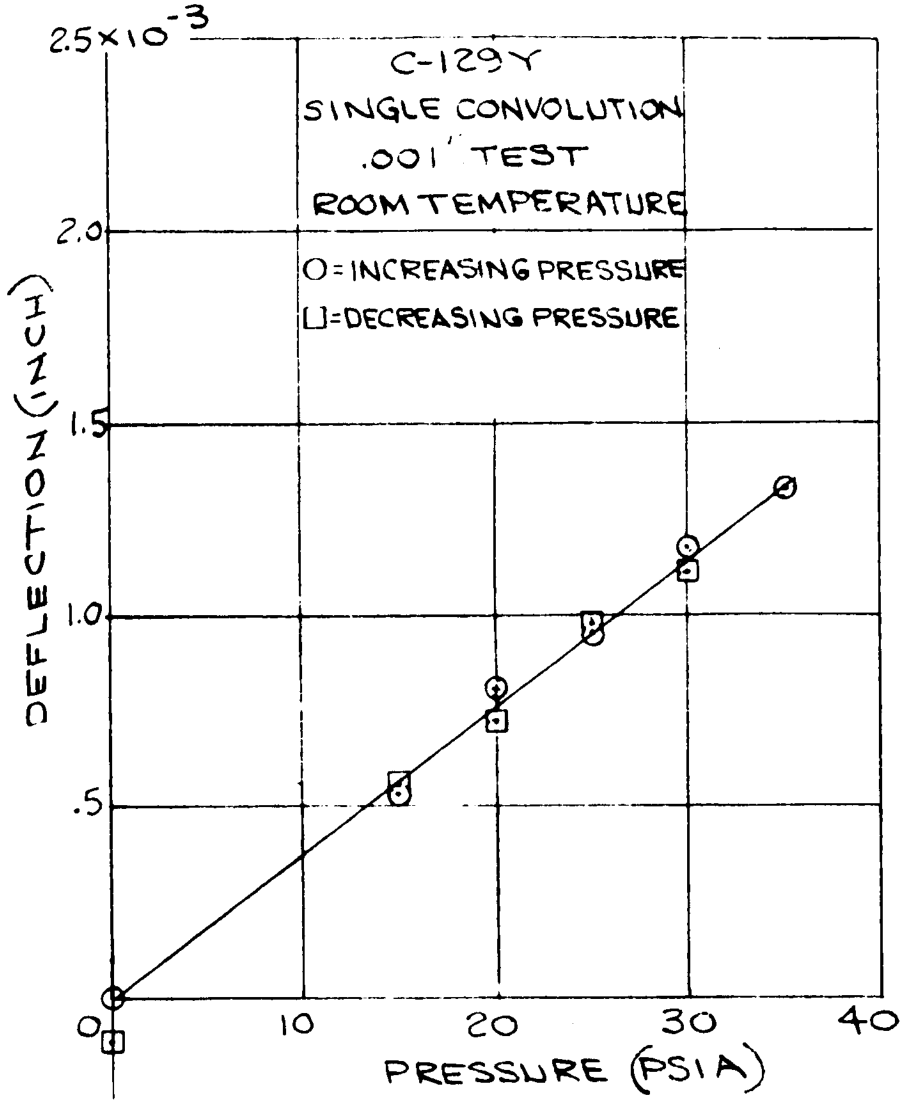

FIGURE 9

C-129Y PRESSURE-DEFLECTION, ROOM TEMPERATURE

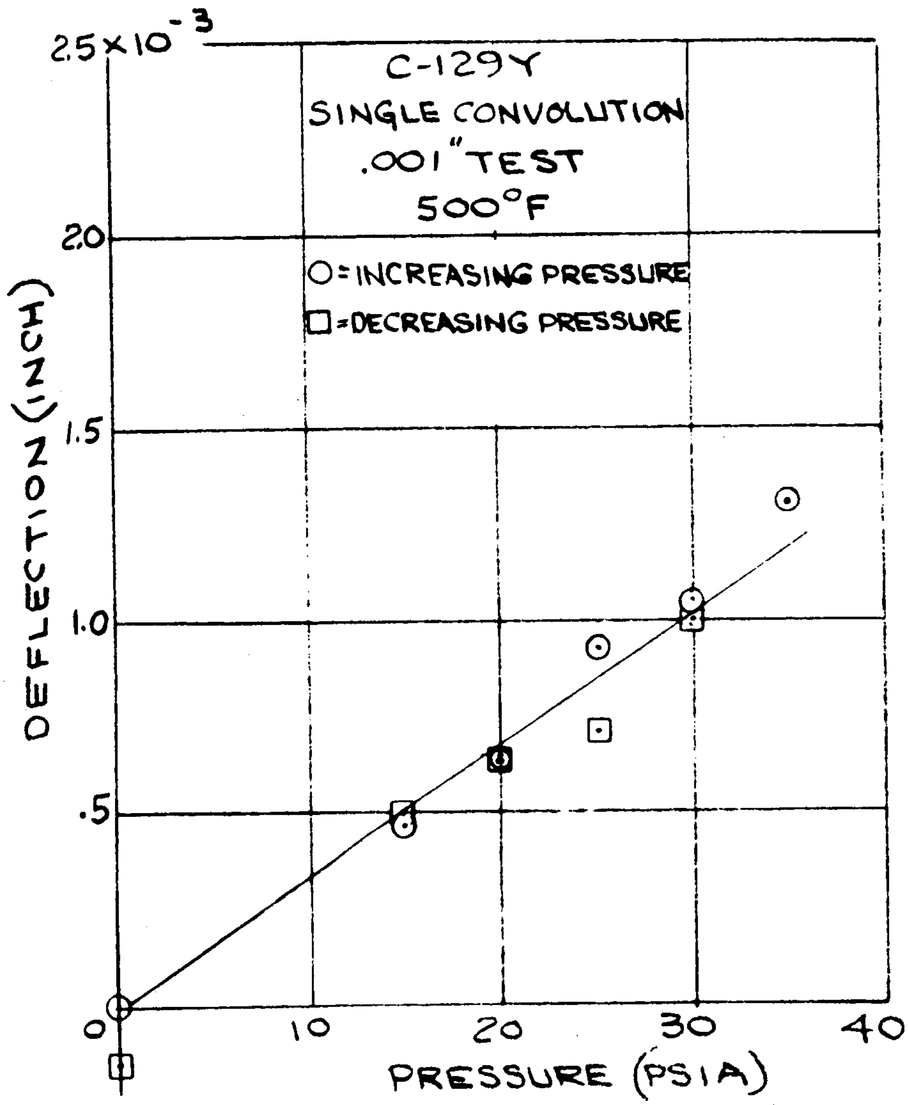

FIGURE 10

C-129Y PRESSURE-DEFLECTION, 500°F

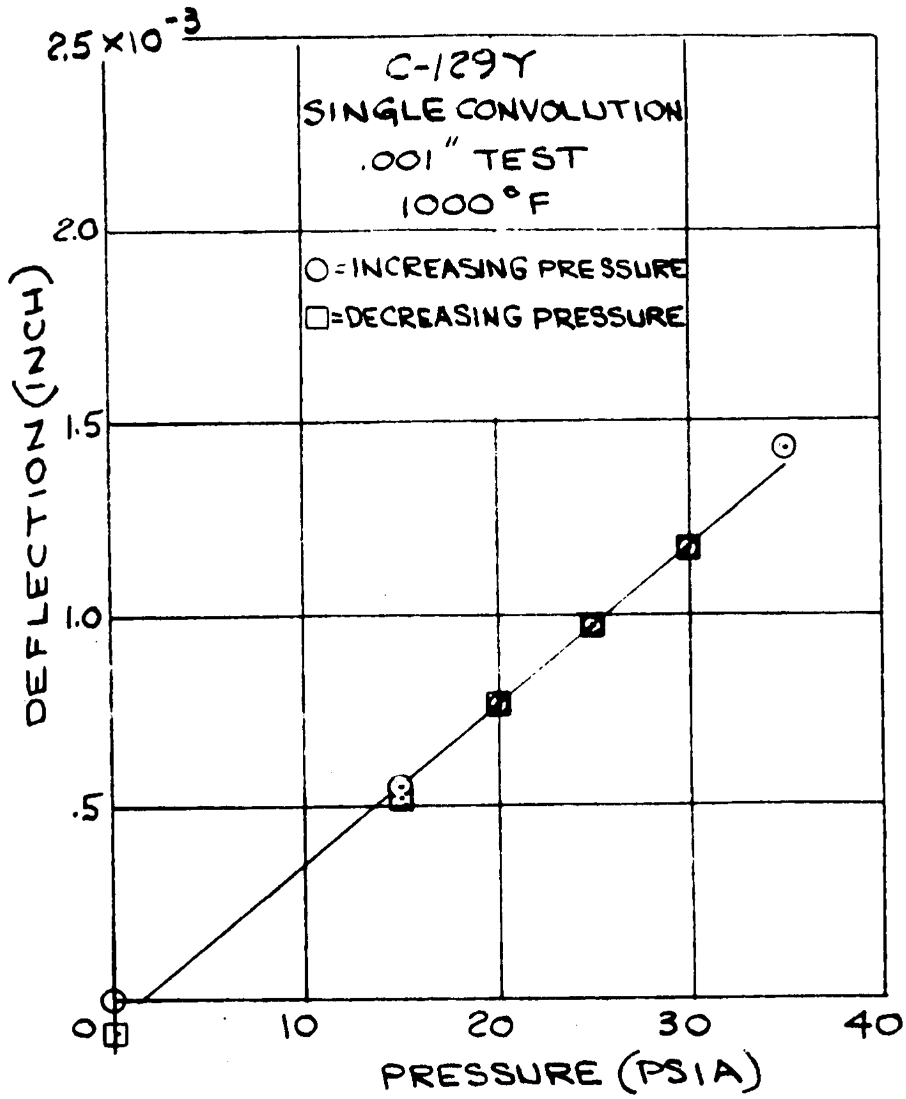

FIGURE 11

C-129Y PRESSURE-DEFLECTION, 1000°F

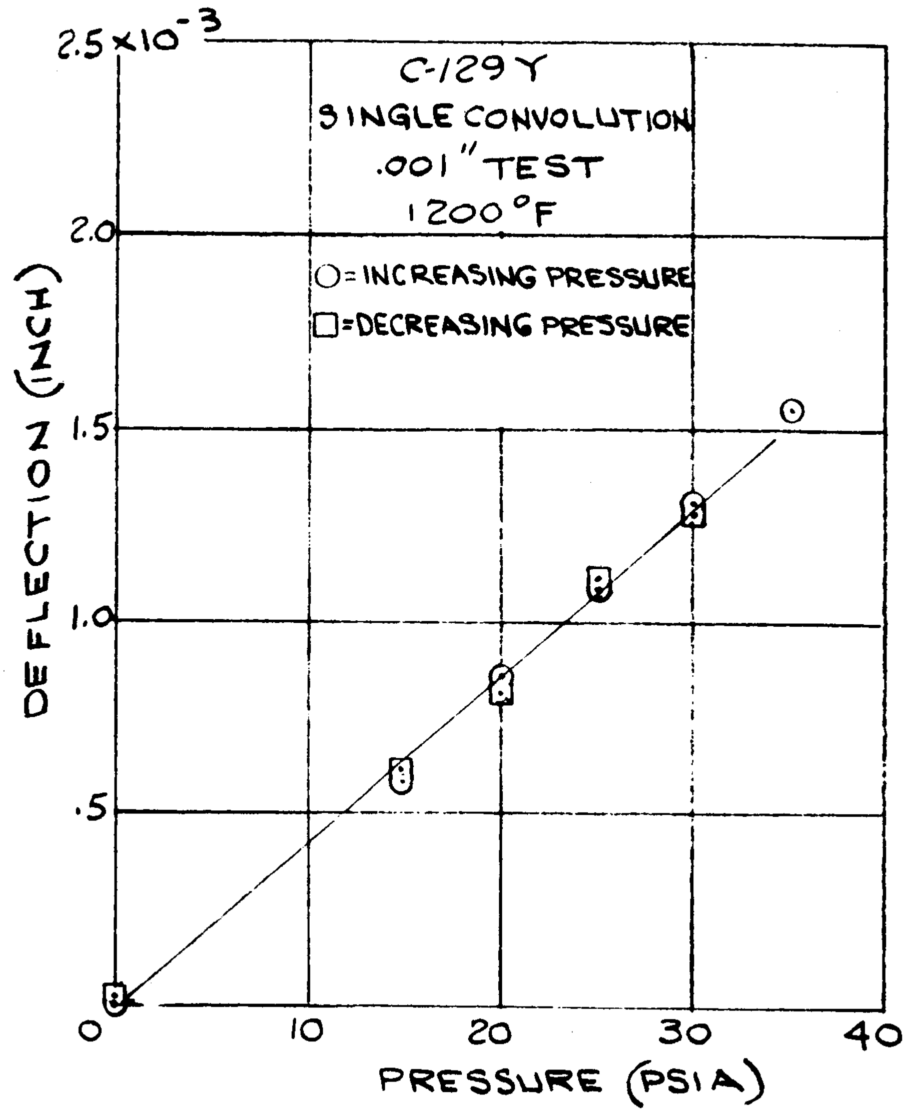

FIGURE 12

C-129Y PRESSURE-DEFLECTION, 1200°F

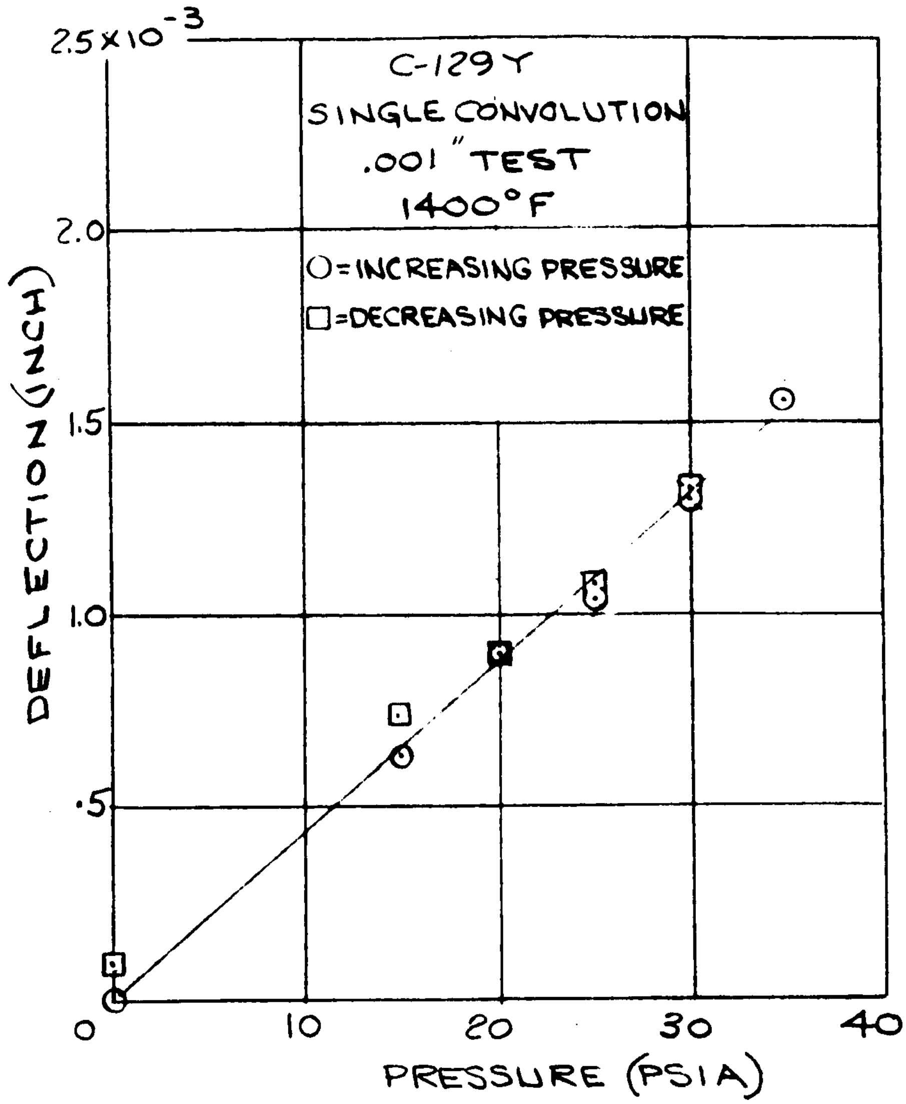

FIGURE 13

C-129Y PRESSURE-DEFLECTION 1400°F

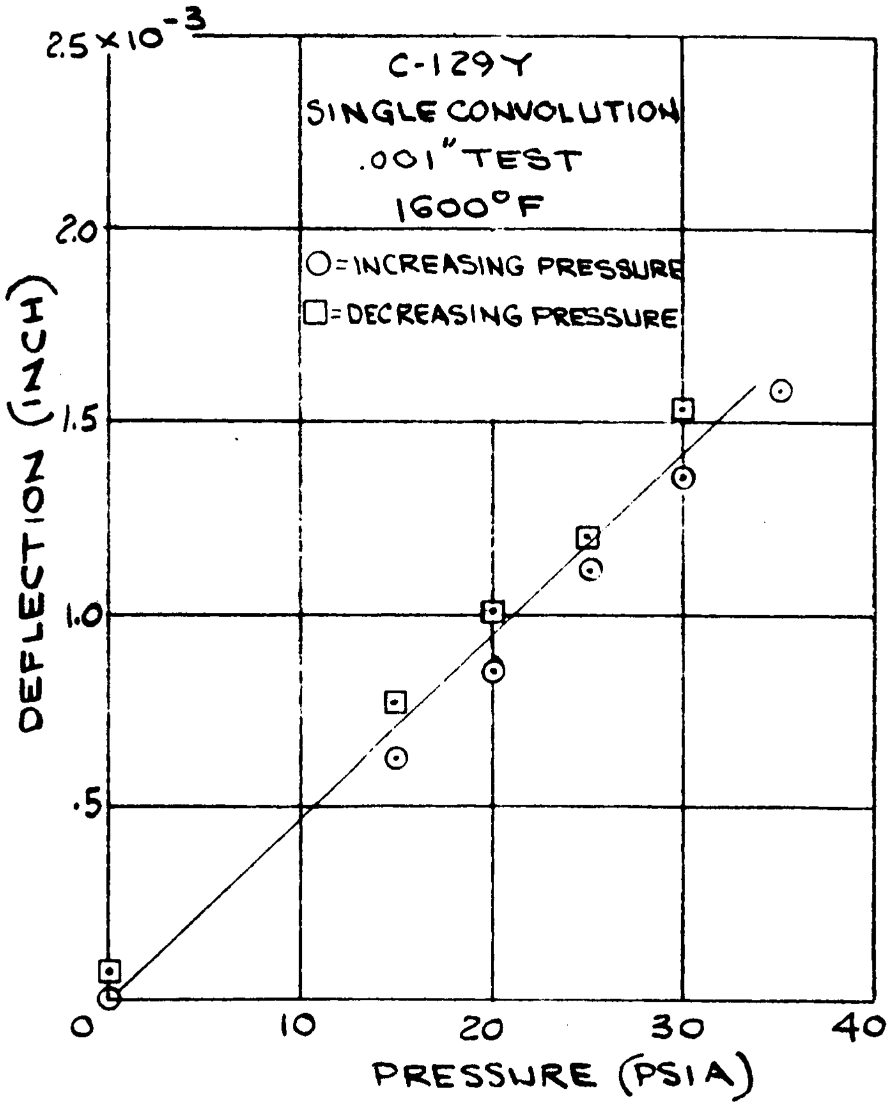

FIGURE 14

C-129Y PRESSURE-DEFLECTION, 1600°F

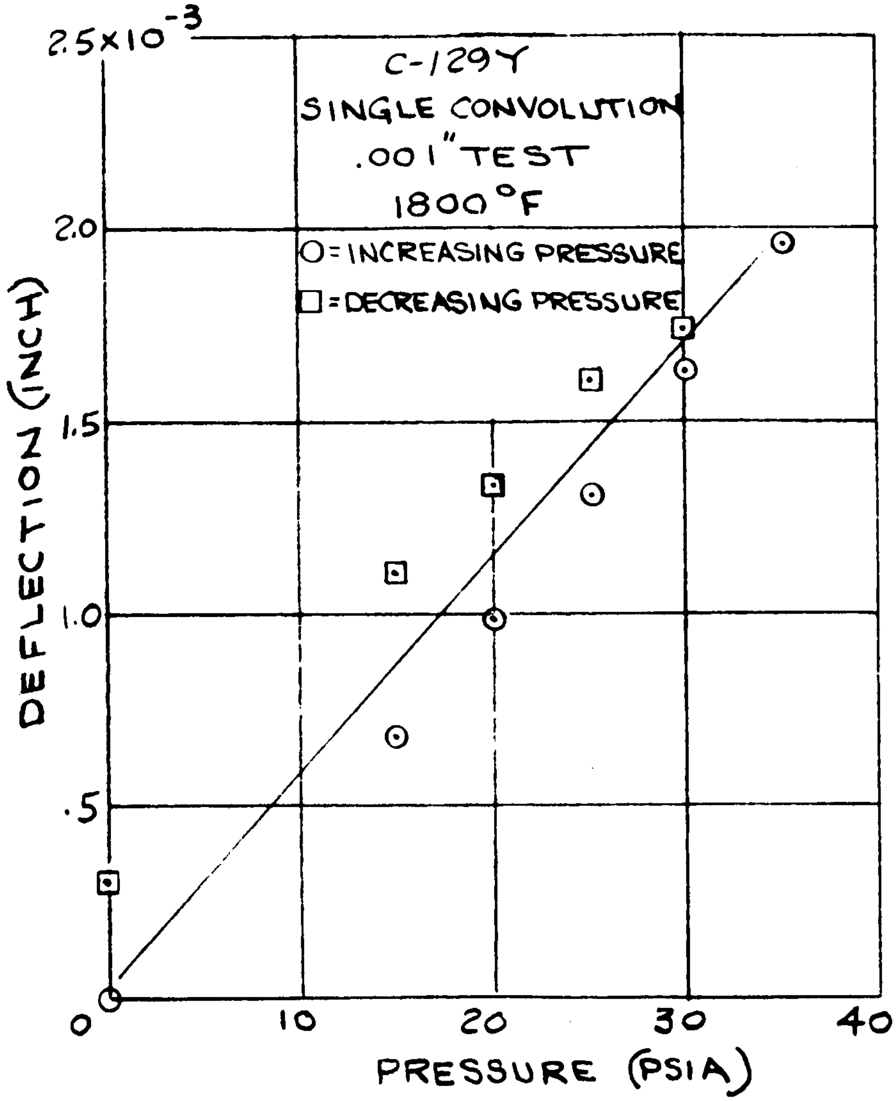

FIGURE 15

C-129Y PRESSURE-DEFLECTION, 1800°F

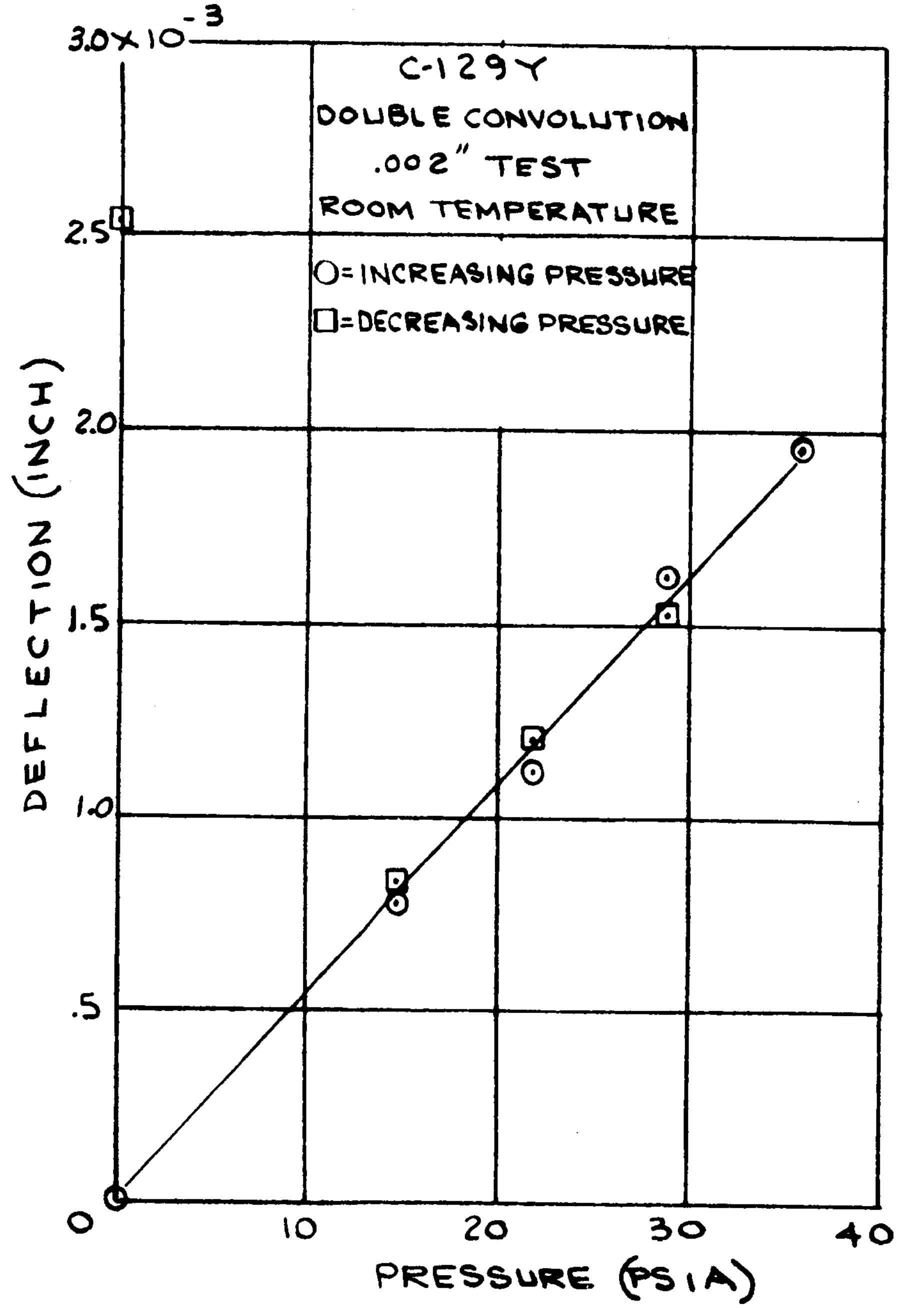

FIGURE 16

C-129Y PRESSURE-DEFLECTION, ROOM TEMPERATURE

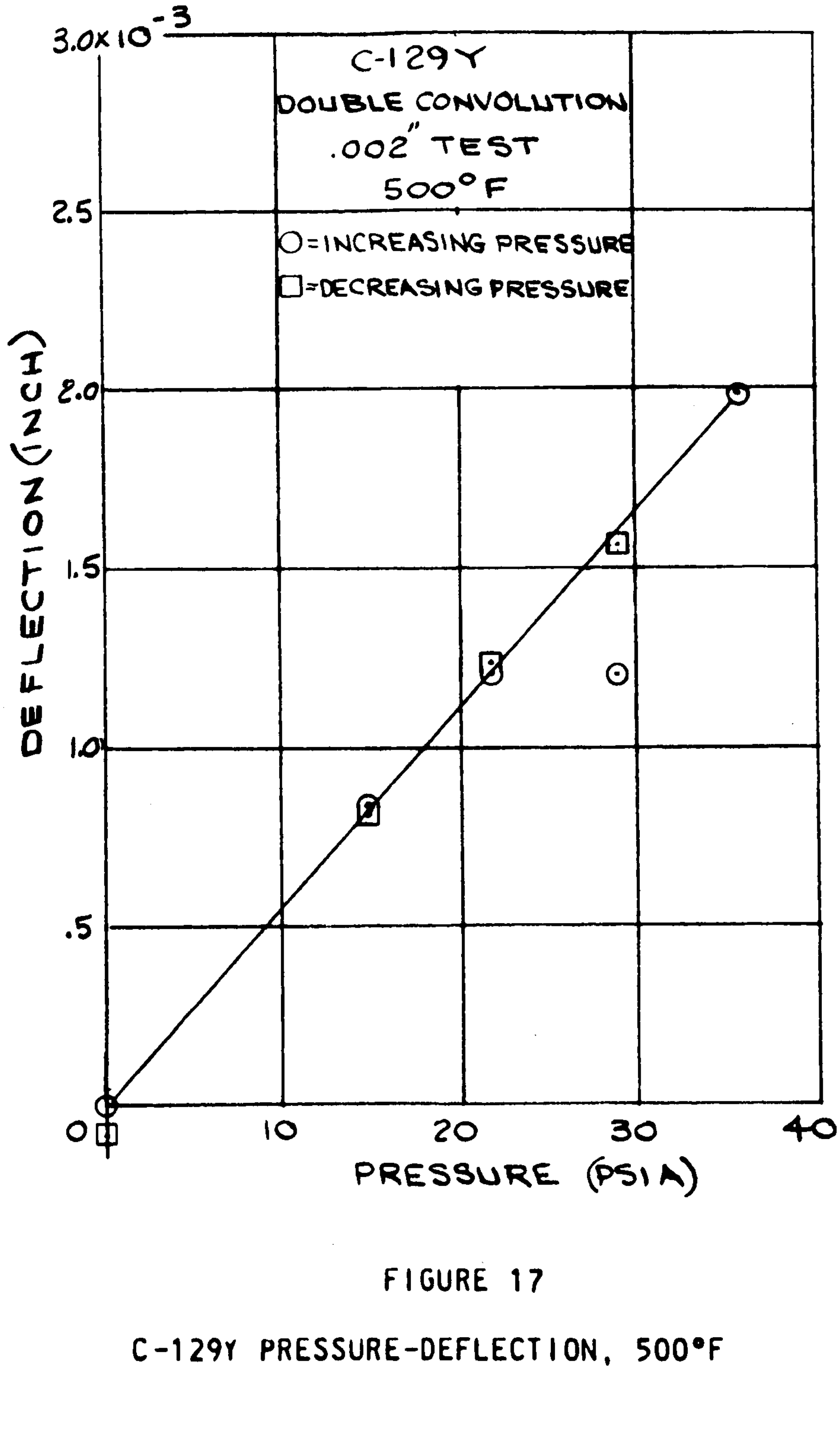

FIGURE 17

C-129Y PRESSURE-DEFLECTION, 500°F

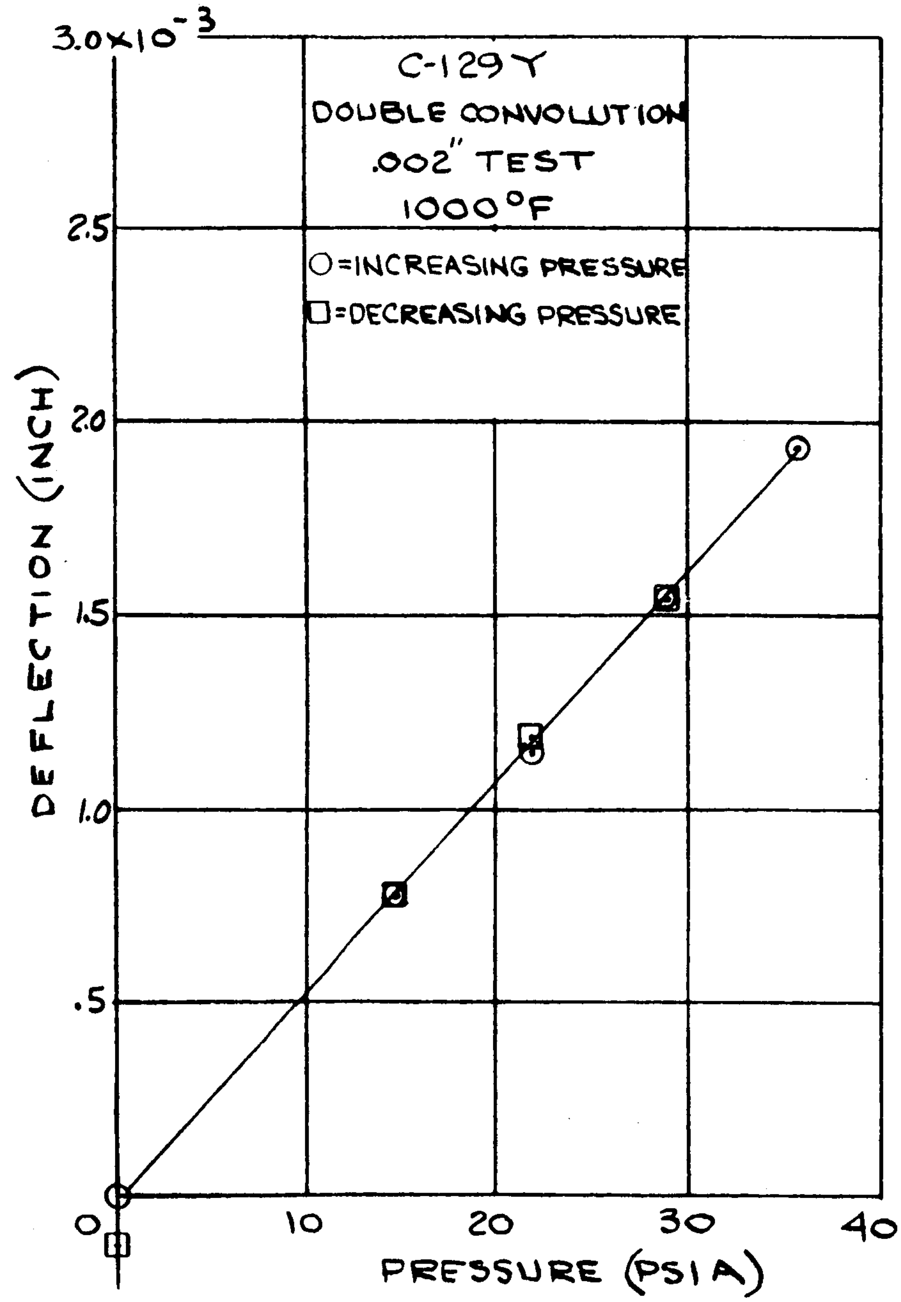

FIGURE 18

C-129Y PRESSURE-DEFLECTION, 1000°F

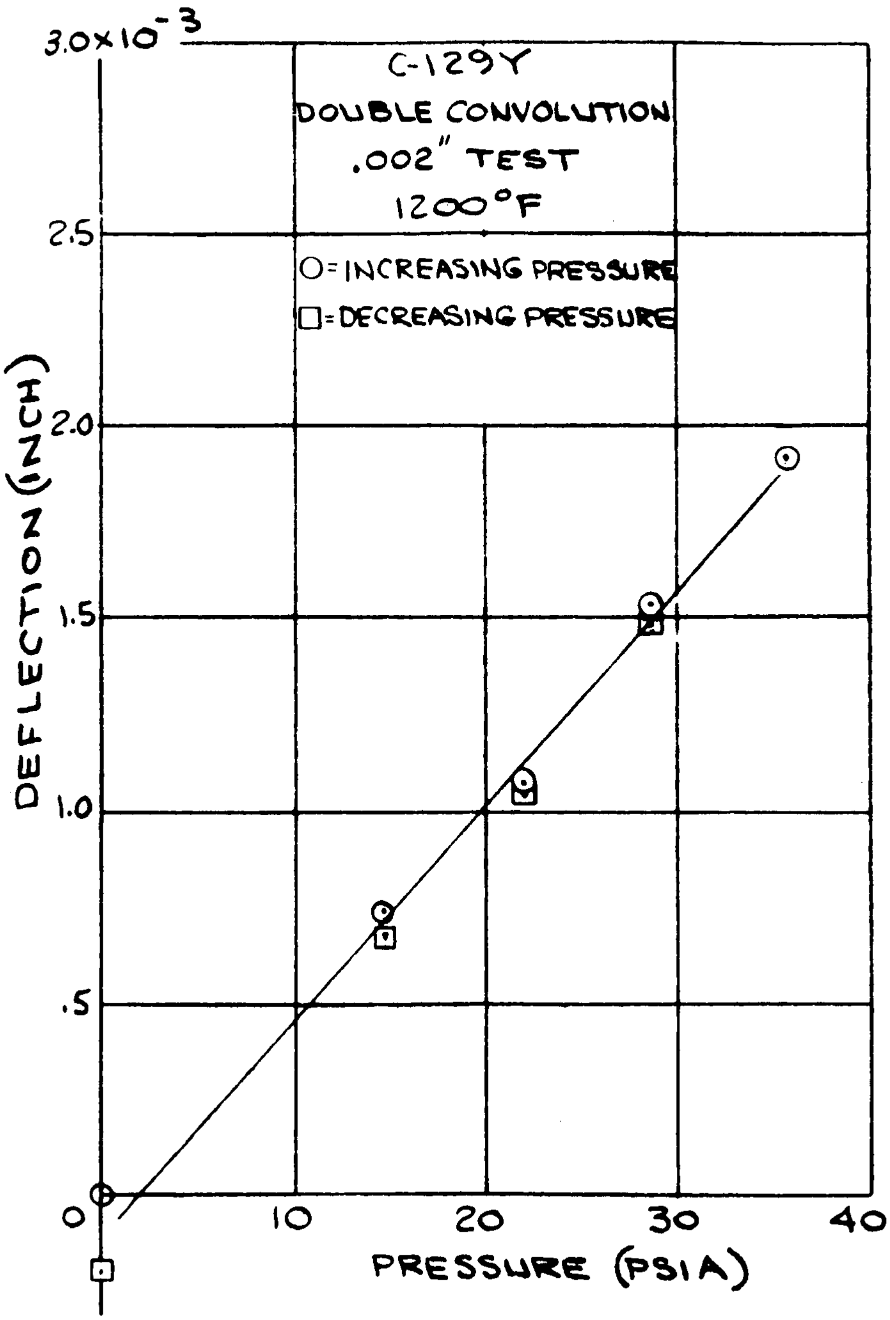

FIGURE 19

C-129Y PRESSURE-DEFLECTION, 1200°F

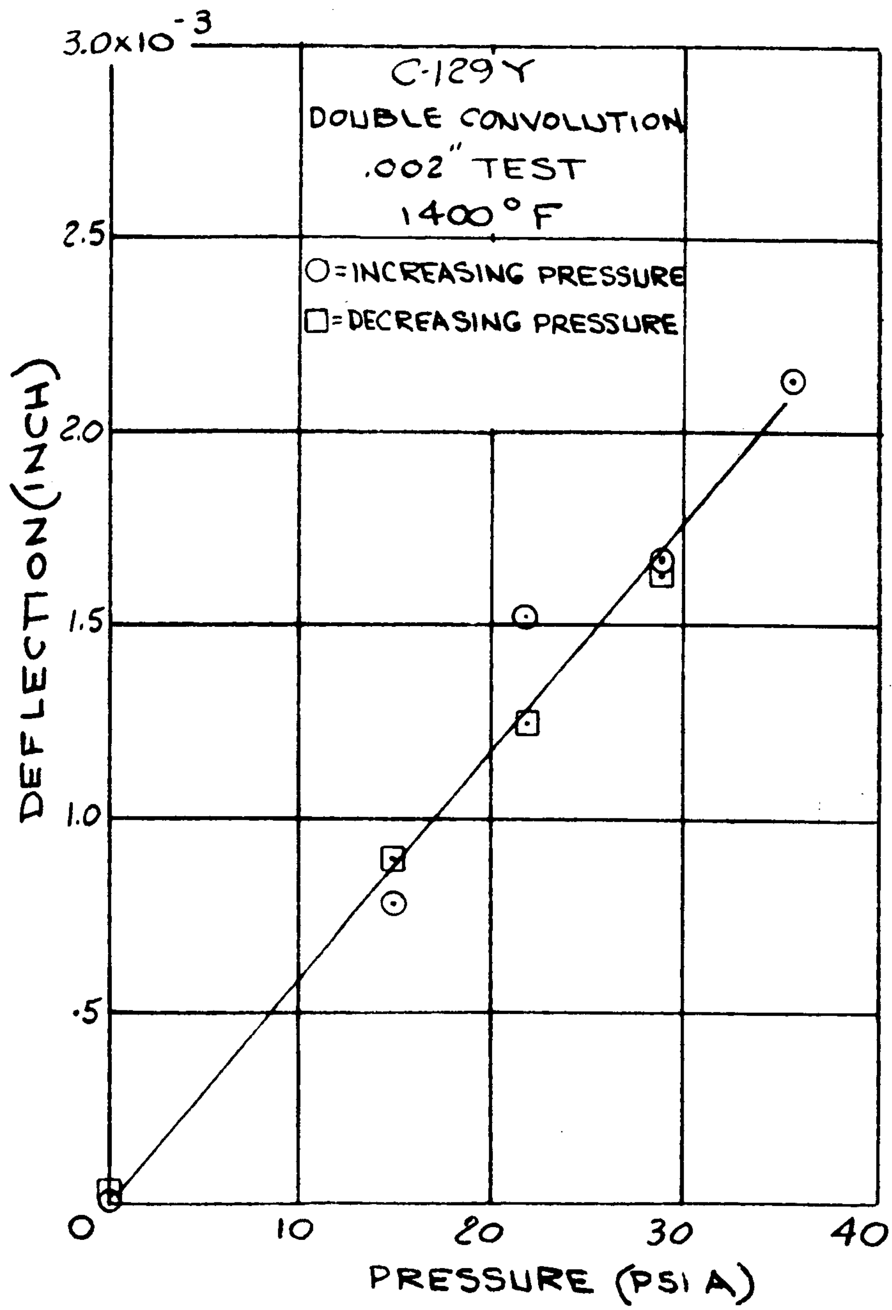

FIGURE 20

C-129Y PRESSURE-DEFLECTION, 1400°F

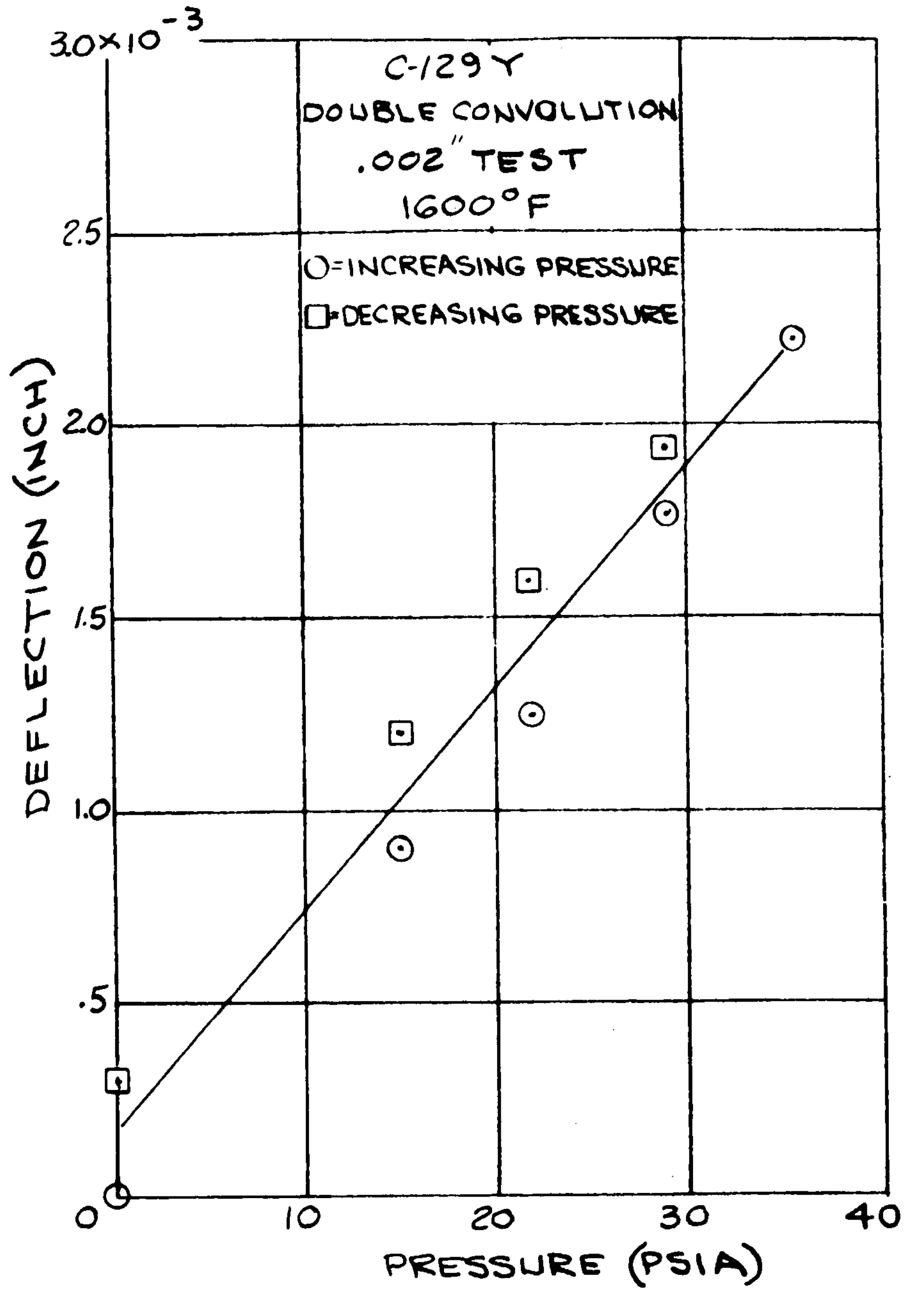

FIGURE 21

C-129Y PRESSURE-DEFLECTION, 1600°F

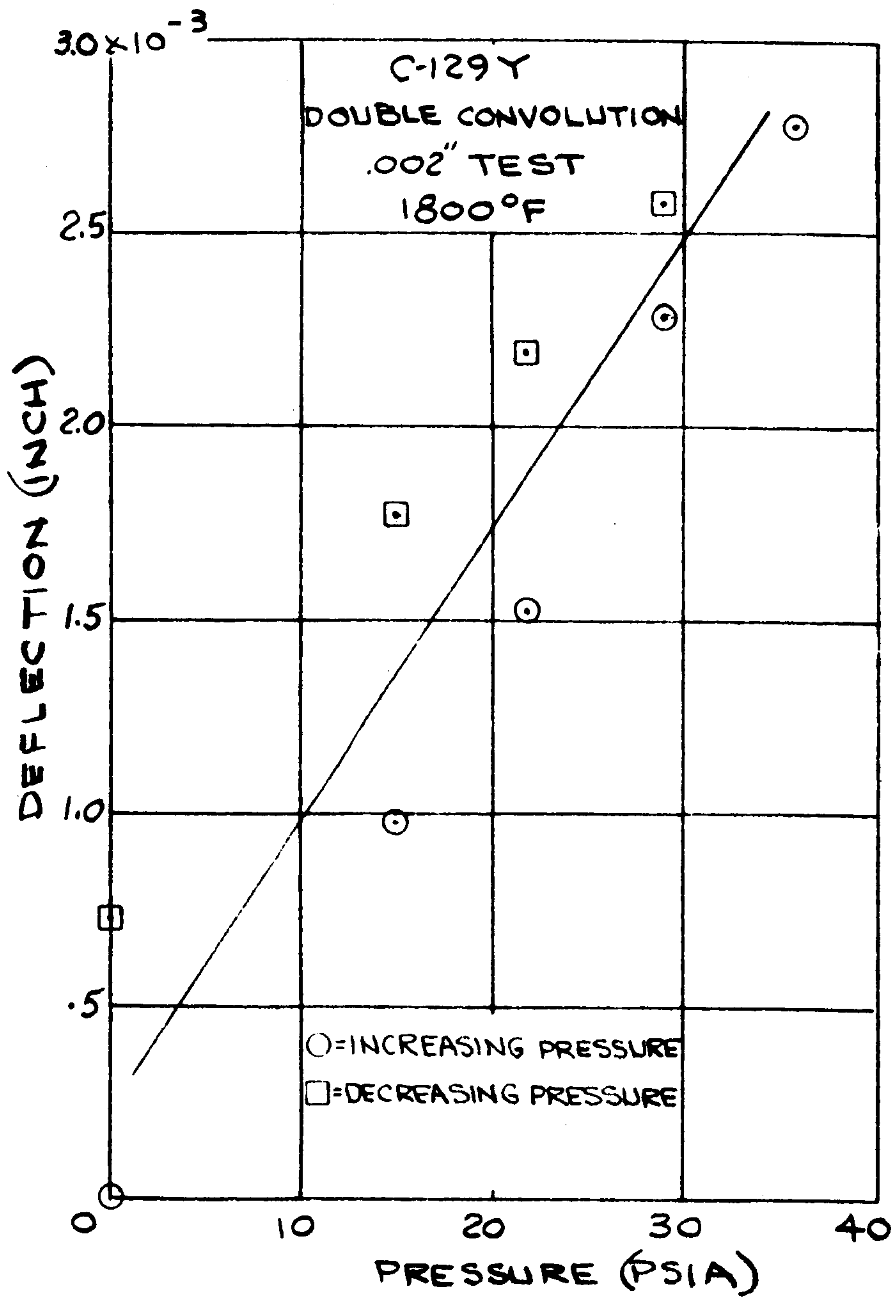

FIGURE 22

C-129Y PRESSURE-DEFLECTION, 1800°F

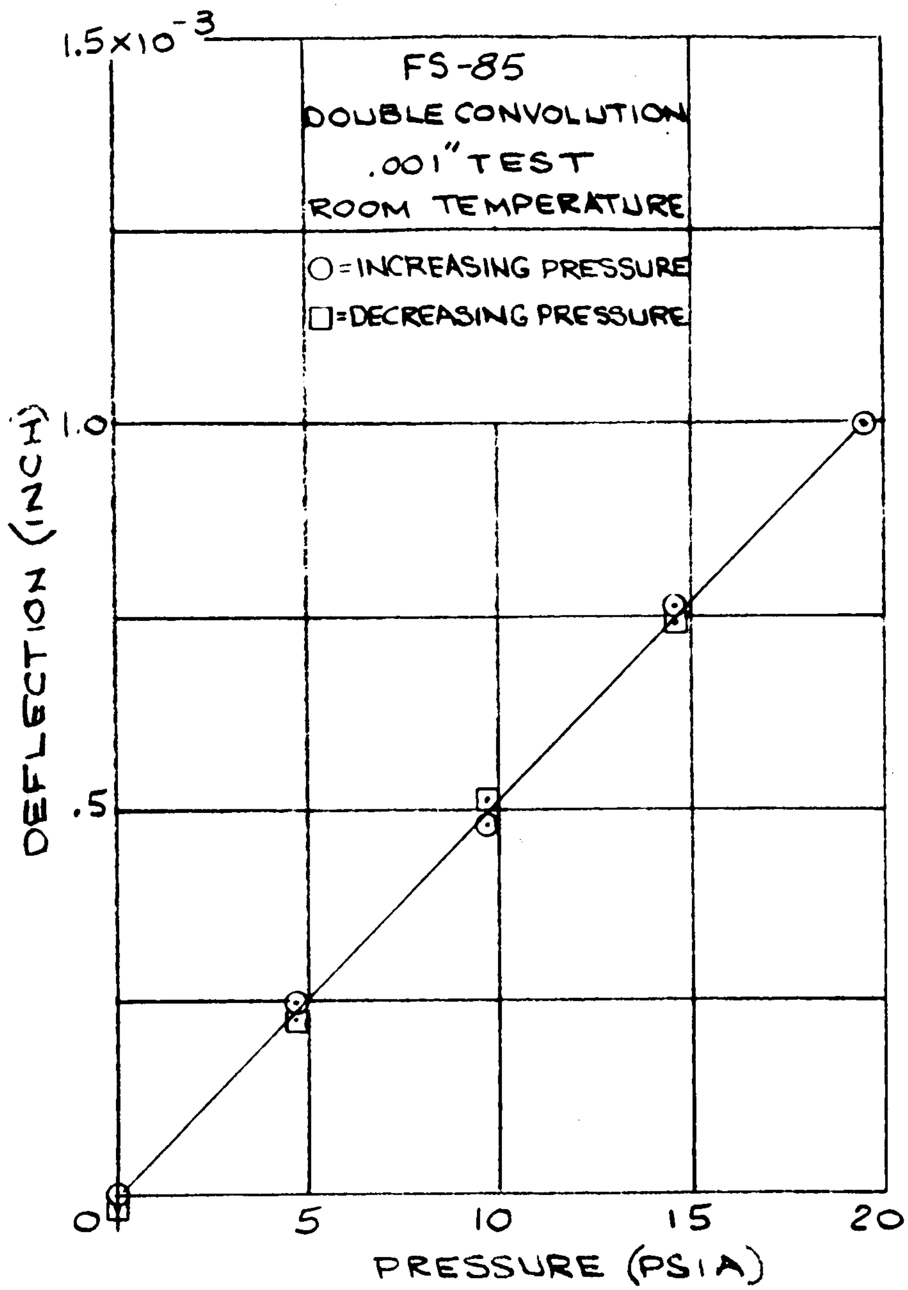

FIGURE 23

FS-85 PRESSURE-DEFLECTION, ROOM TEMPERATURE

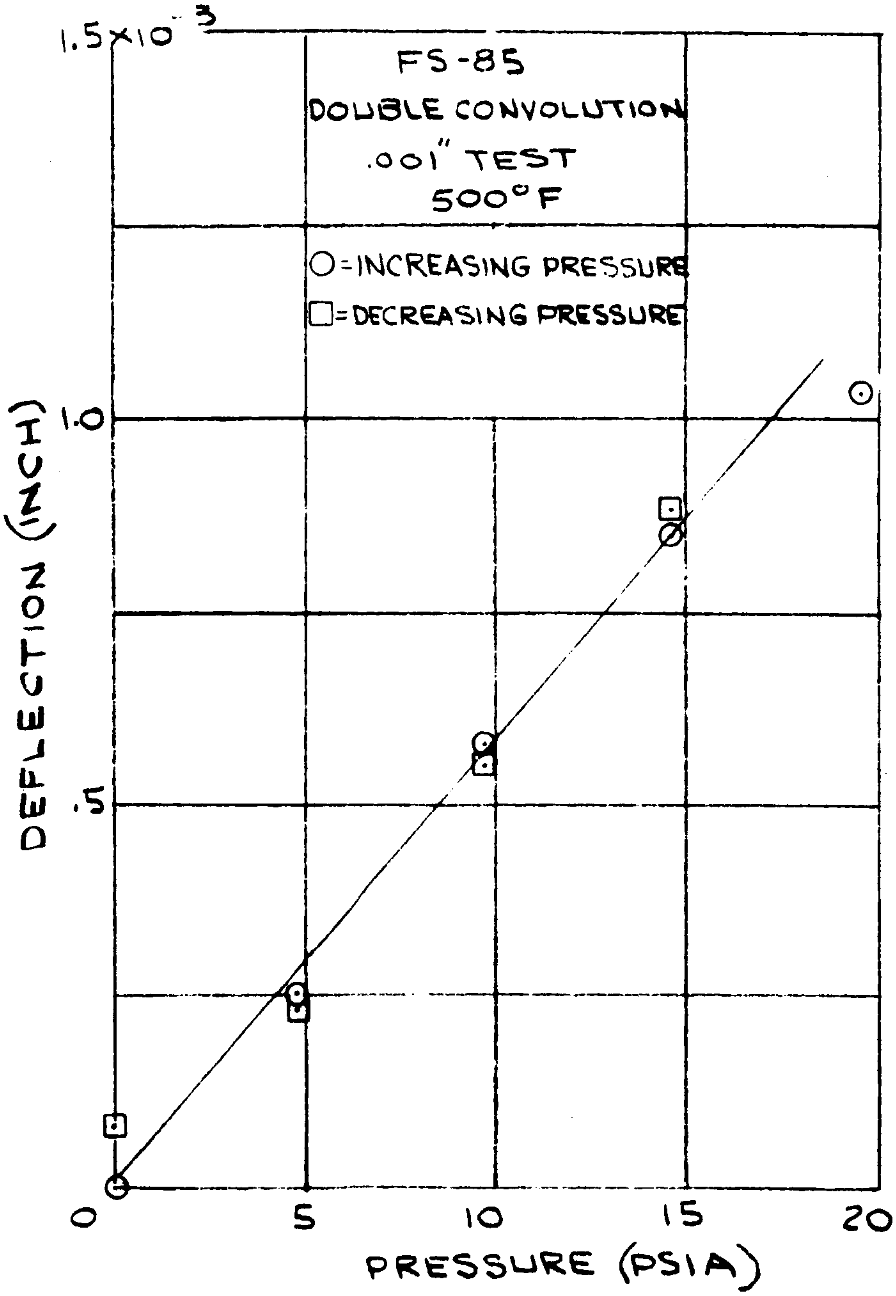

FIGURE 24

FS-85 PRESSURE-DEFLECTION, 500°F

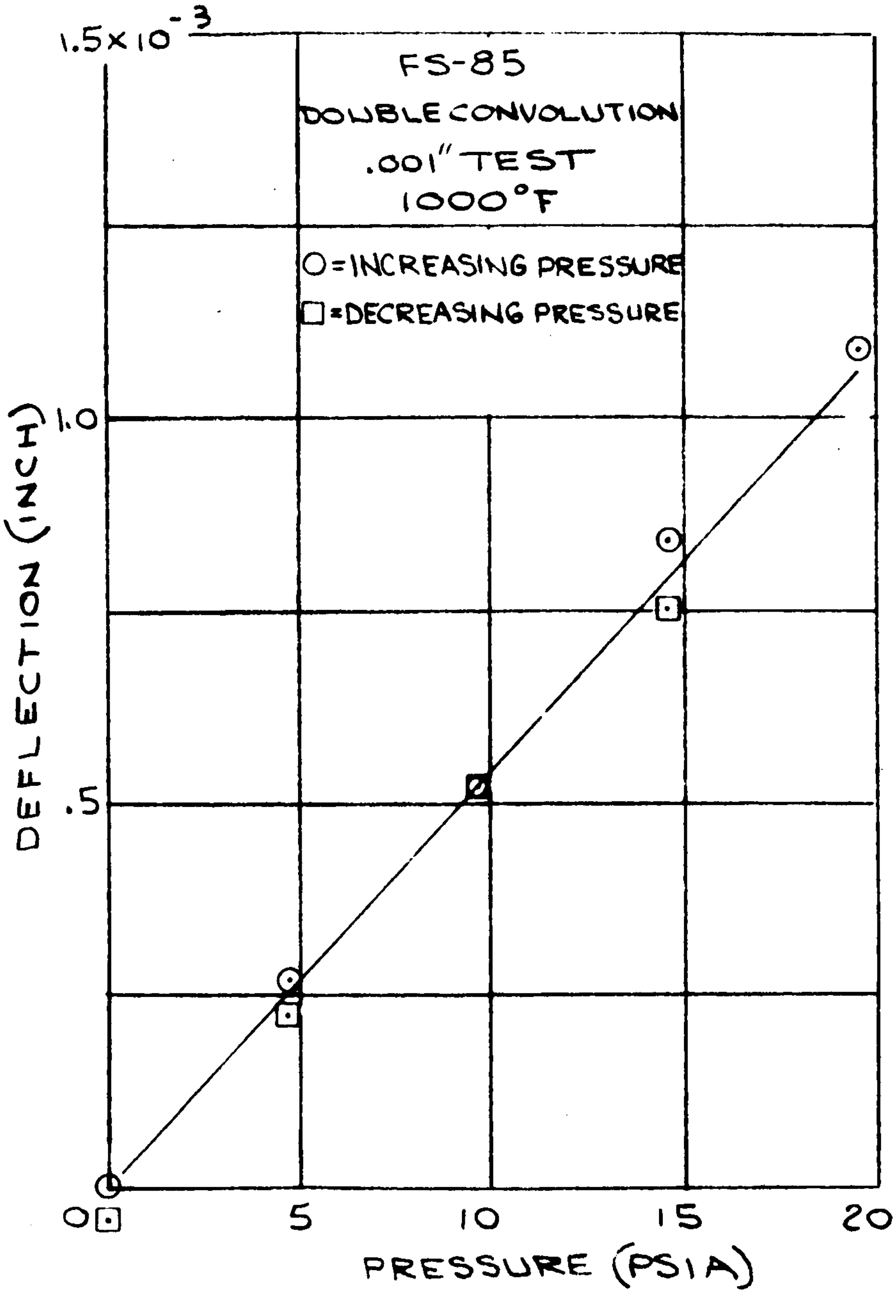

FIGURE 25

FS-85 PRESSURE-DEFLECTION, 1000°F

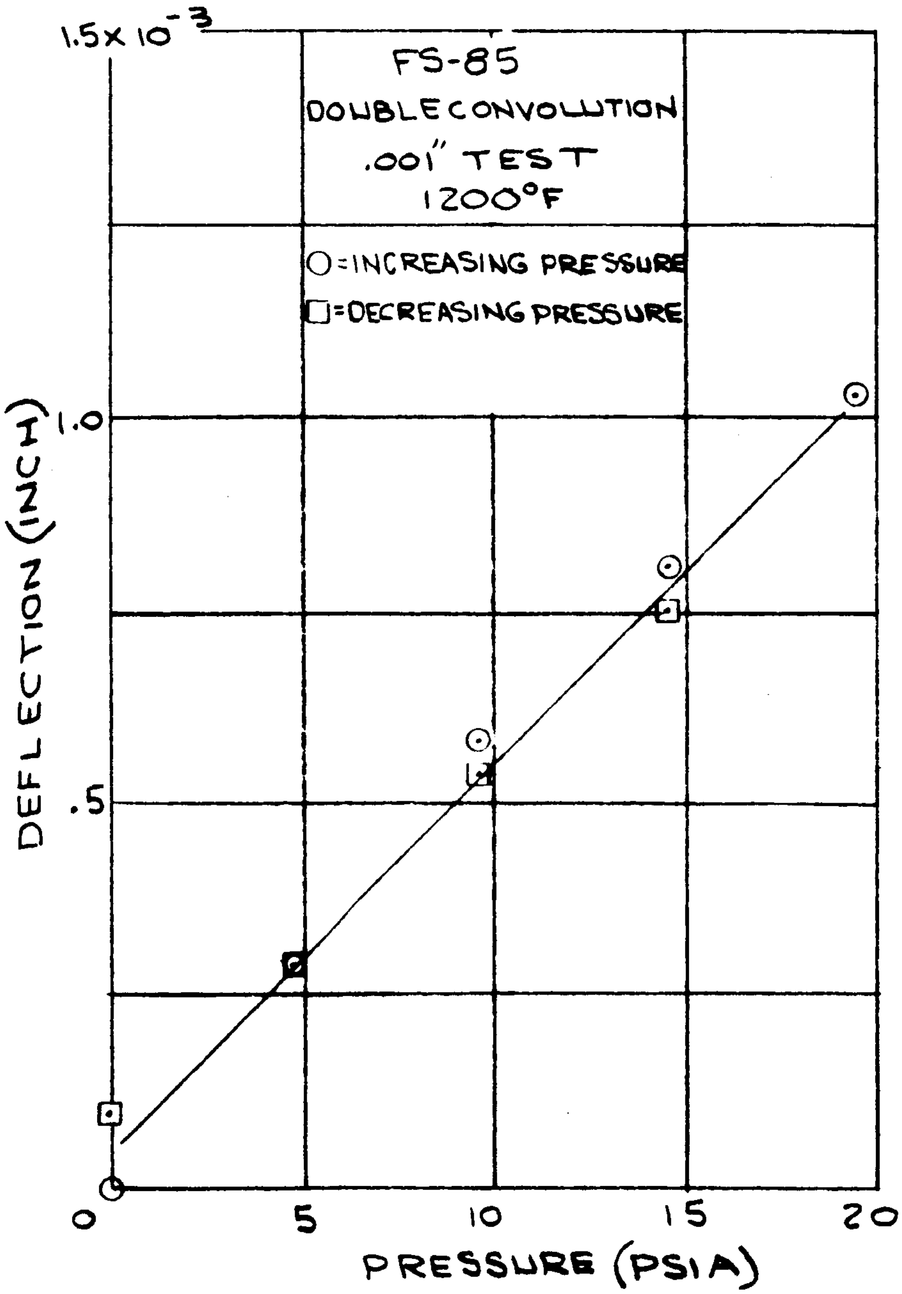

FIGURE 26

FS-85 PRESSURE-DEFLECTION, 1200°F

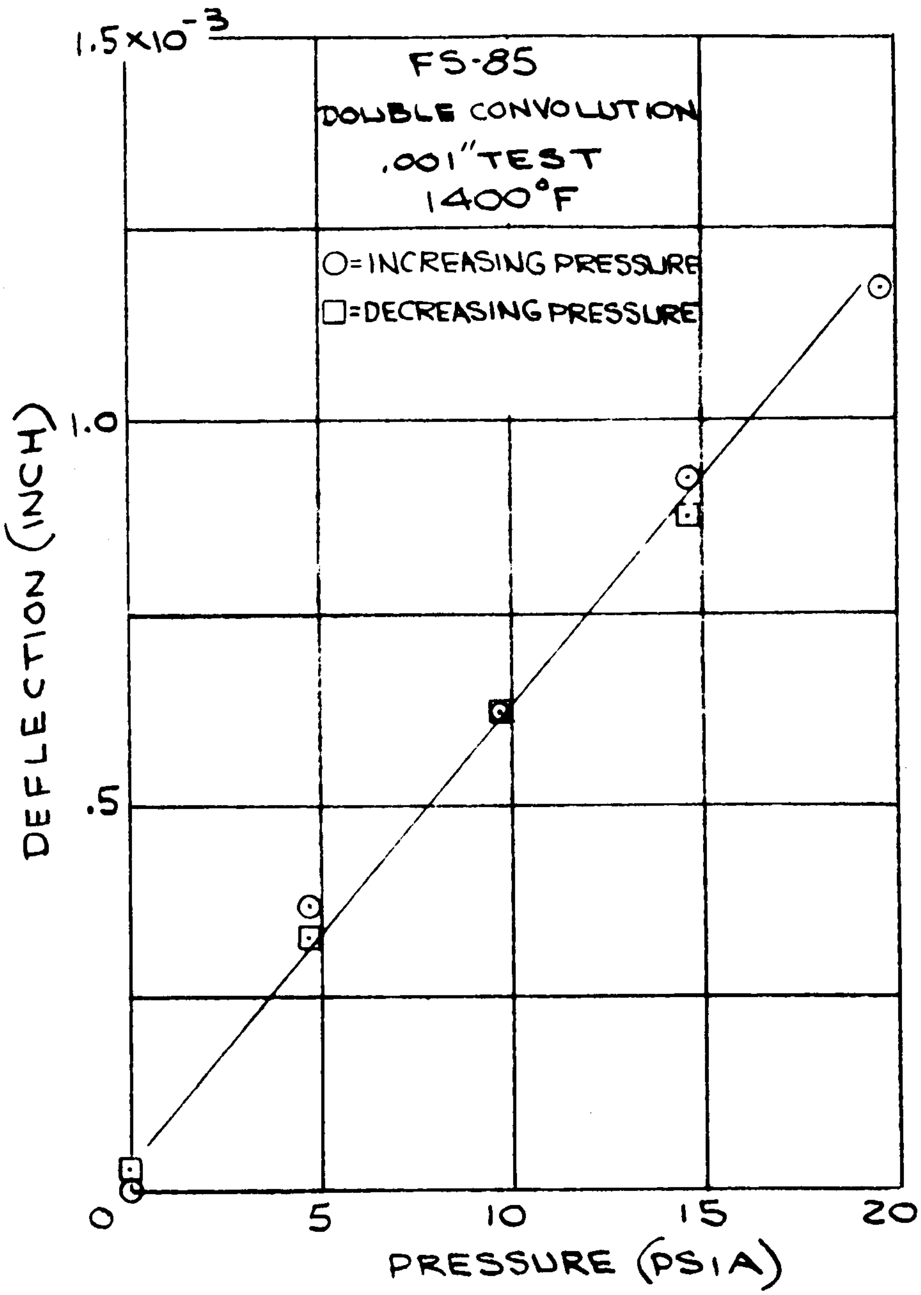

FIGURE 27

FS-85 PRESSURE-DEFLECTION, 1400°F

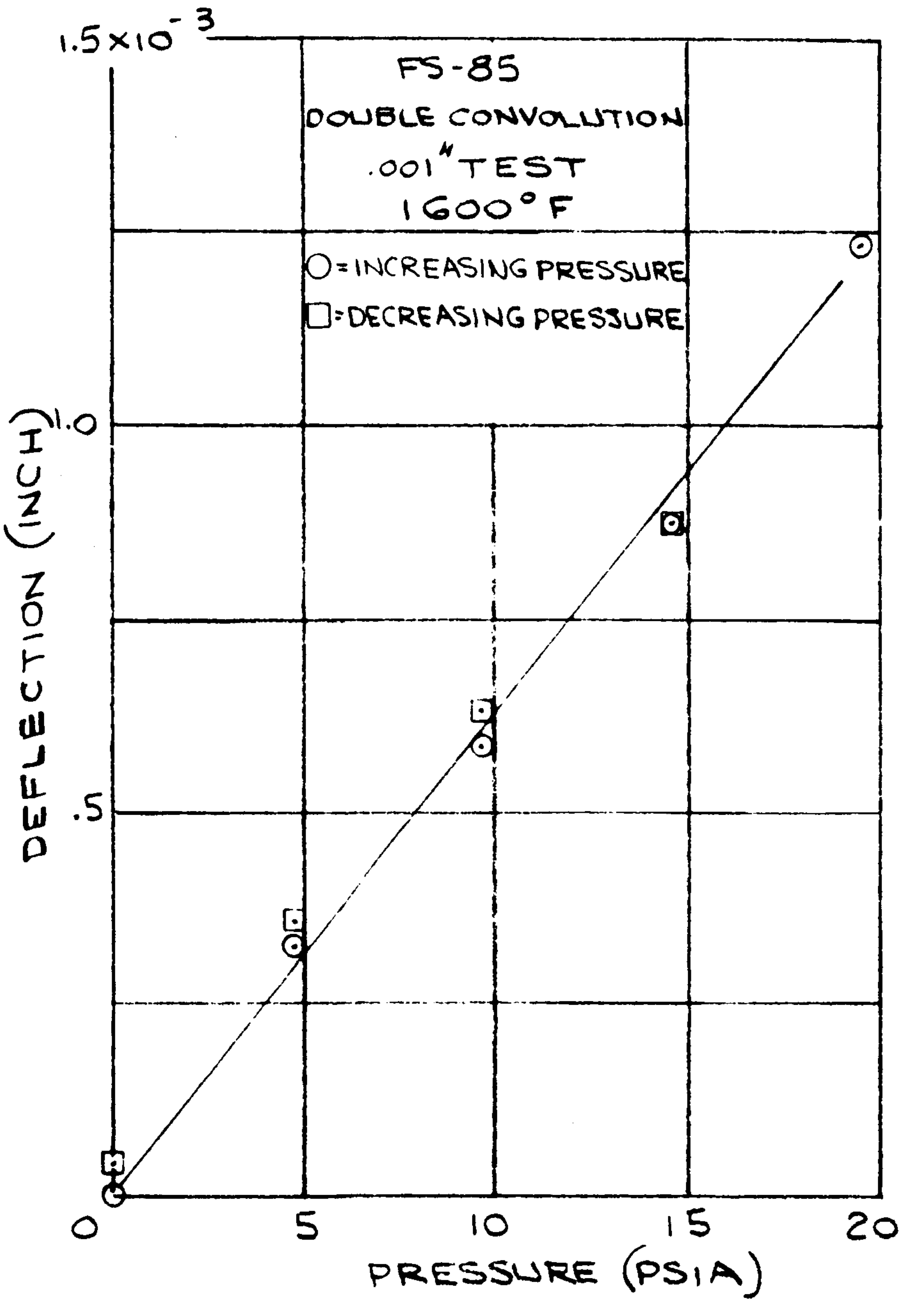

FIGURE 28

FS-85 PRESSURE-DEFLECTION, 1600°F

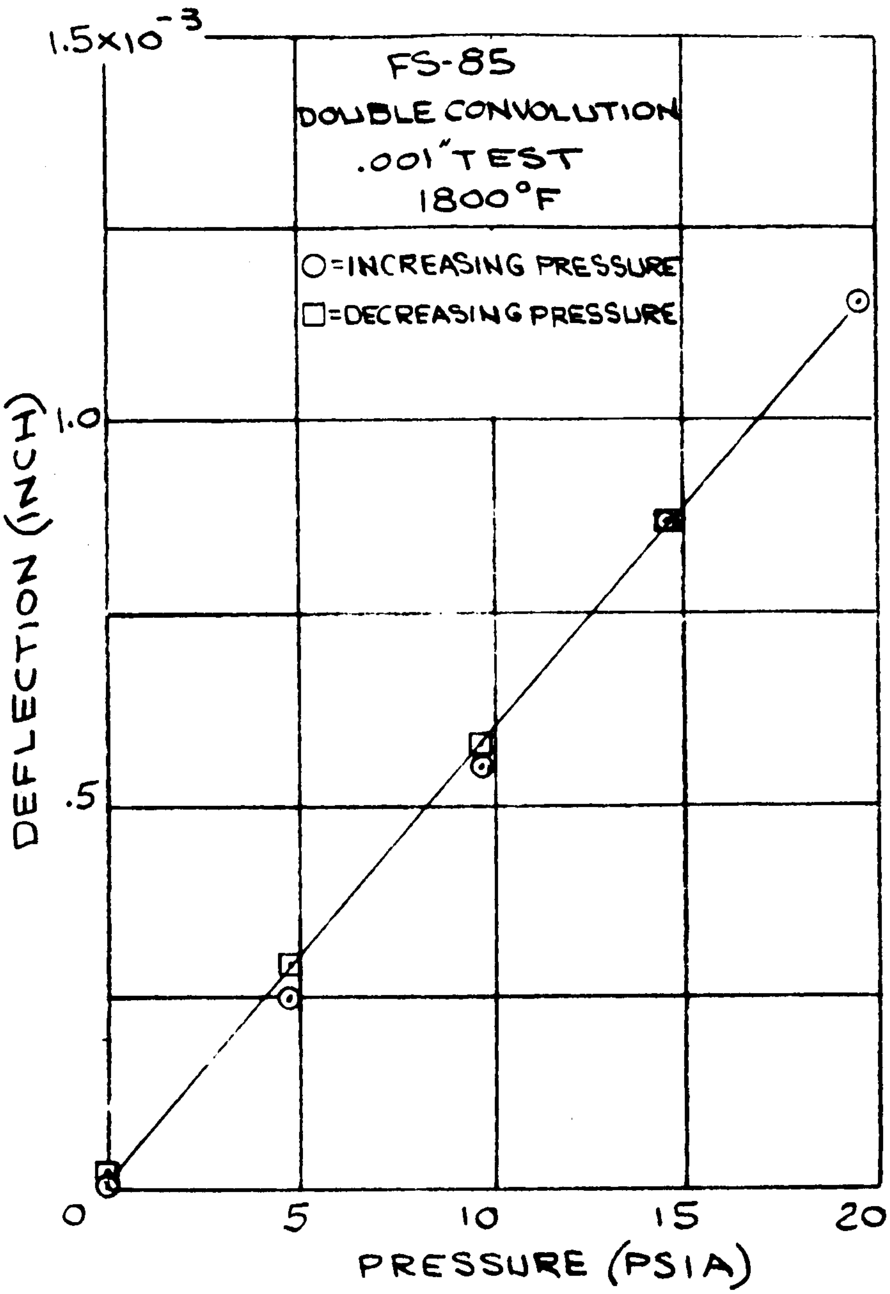

FIGURE 29

FS-85 PRESSURE-DEFLECTION, 1800°F

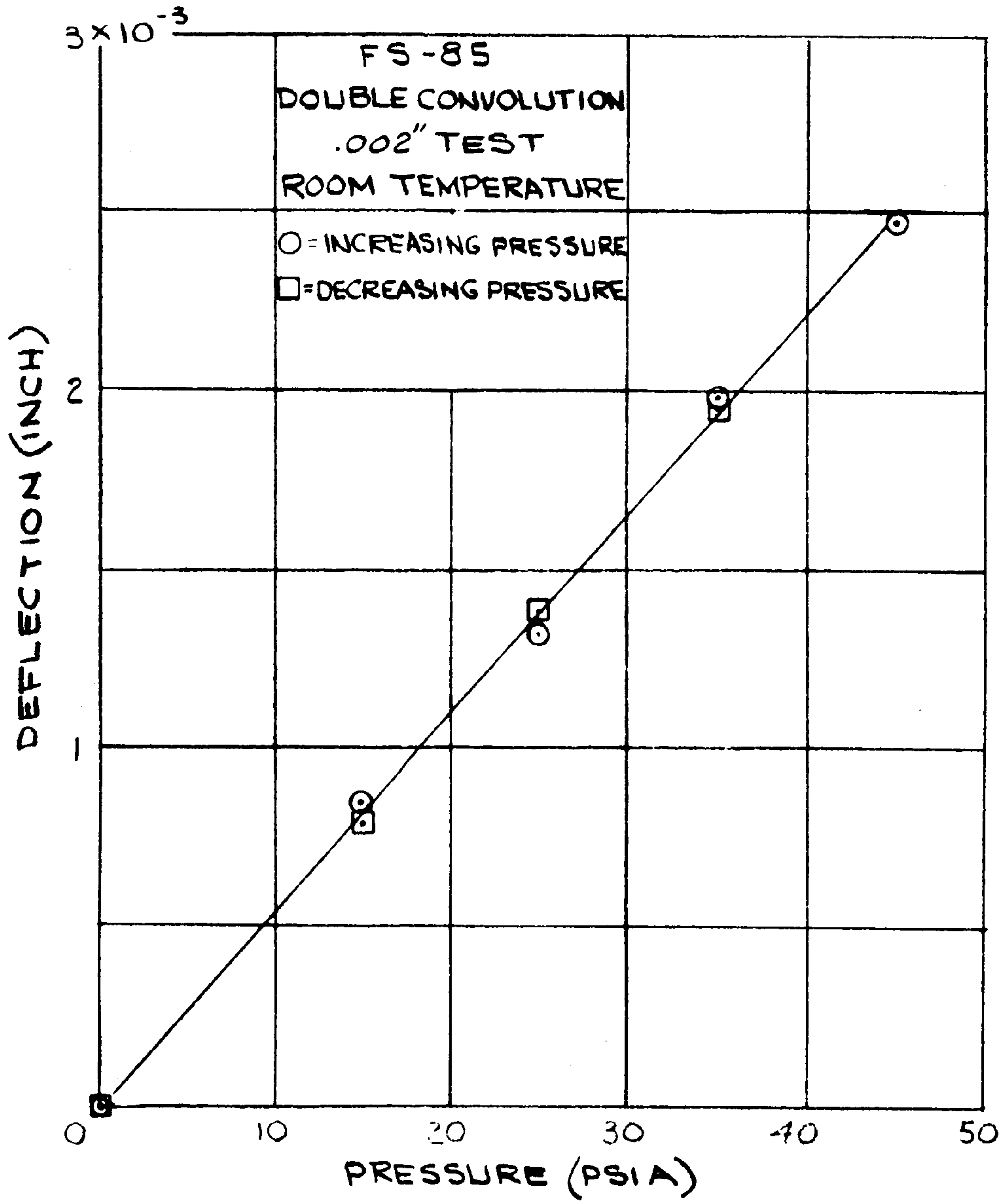

FIGURE 30

FS-85 PRESSURE-DEFLECTION, ROOM TEMPERATURE

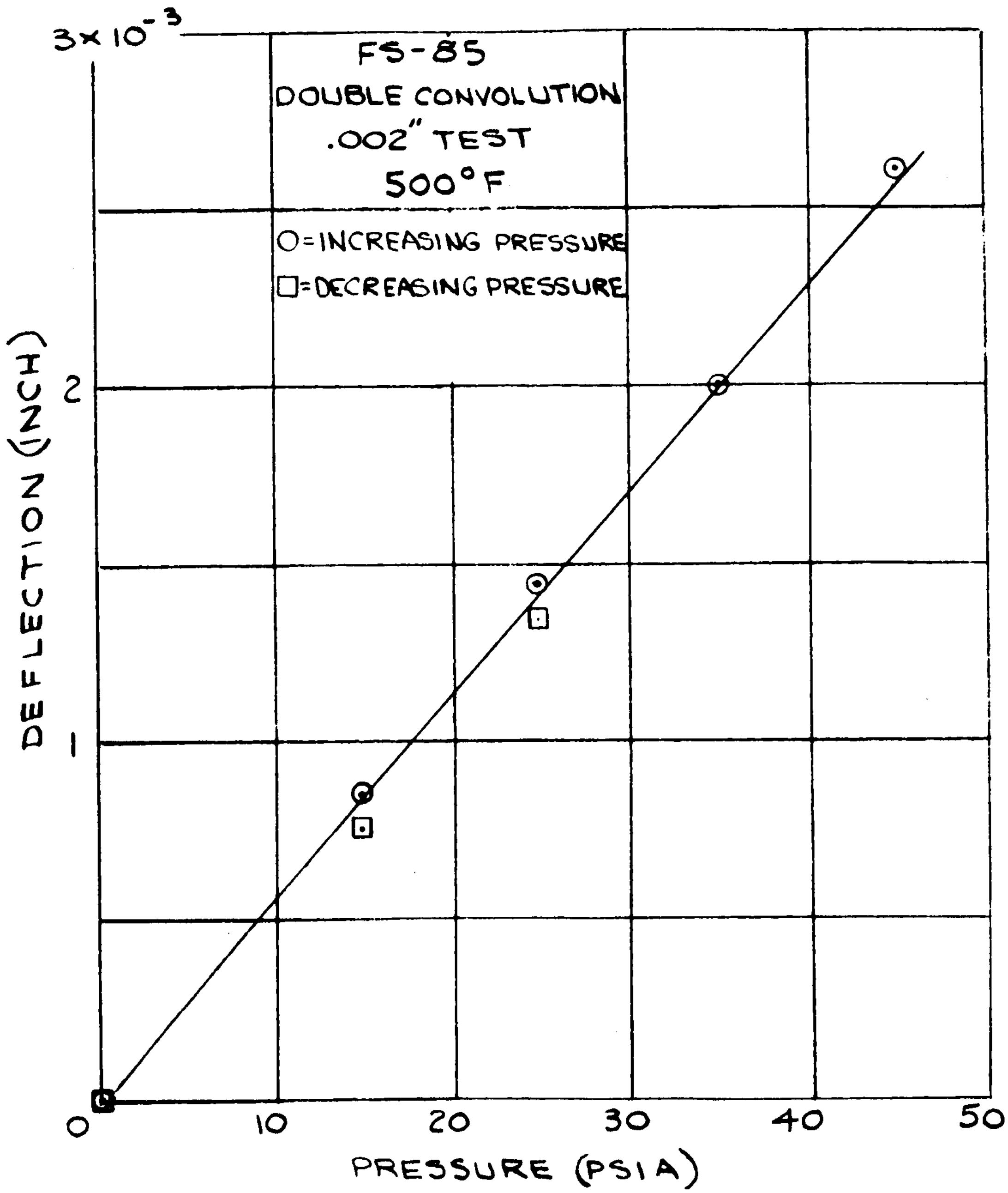

FIGURE 31

FS-85 PRESSURE-DEFLECTION, 500°F

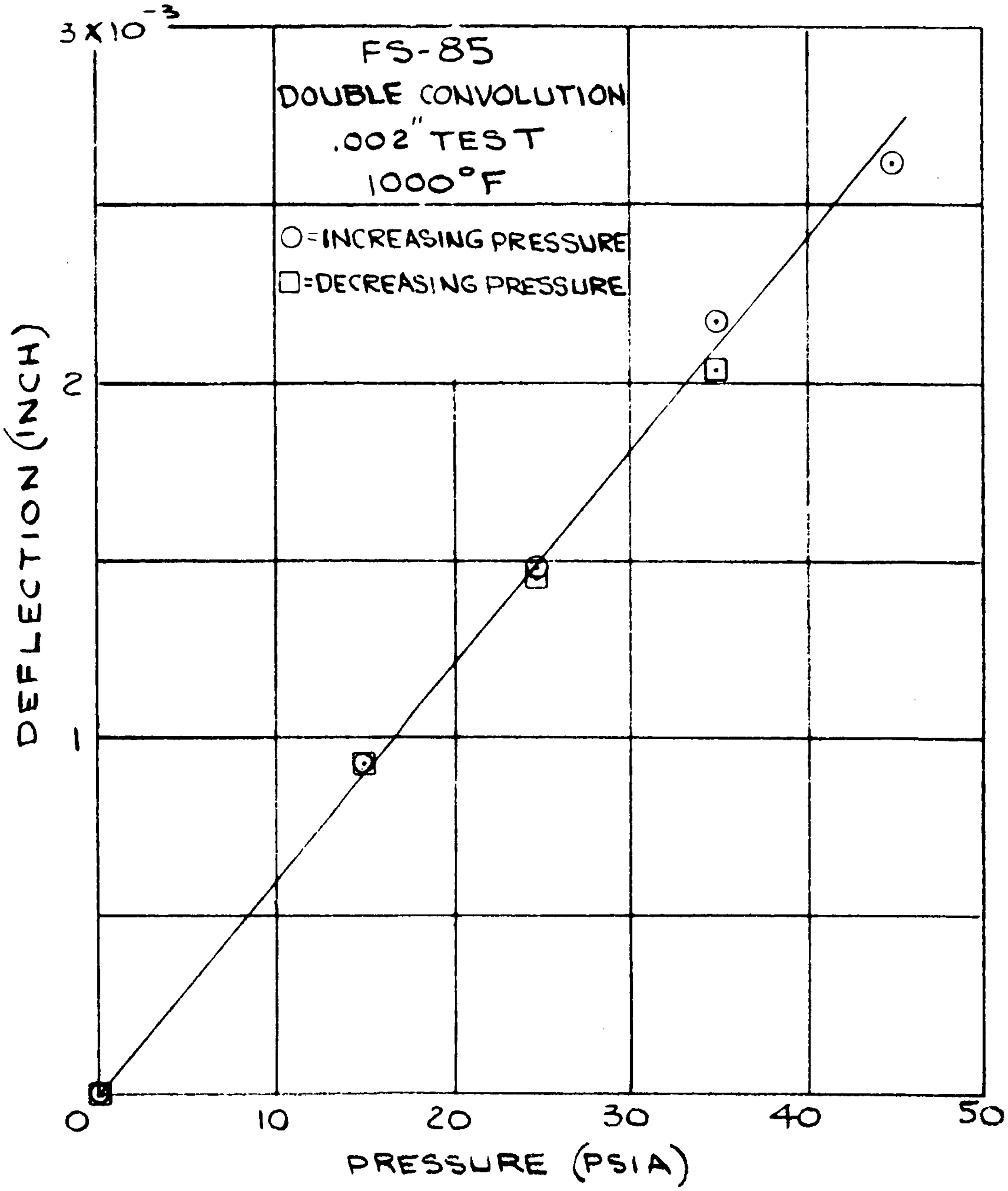

FIGURE 32

FS-85 PRESSURE-DEFLECTION, 1000°F

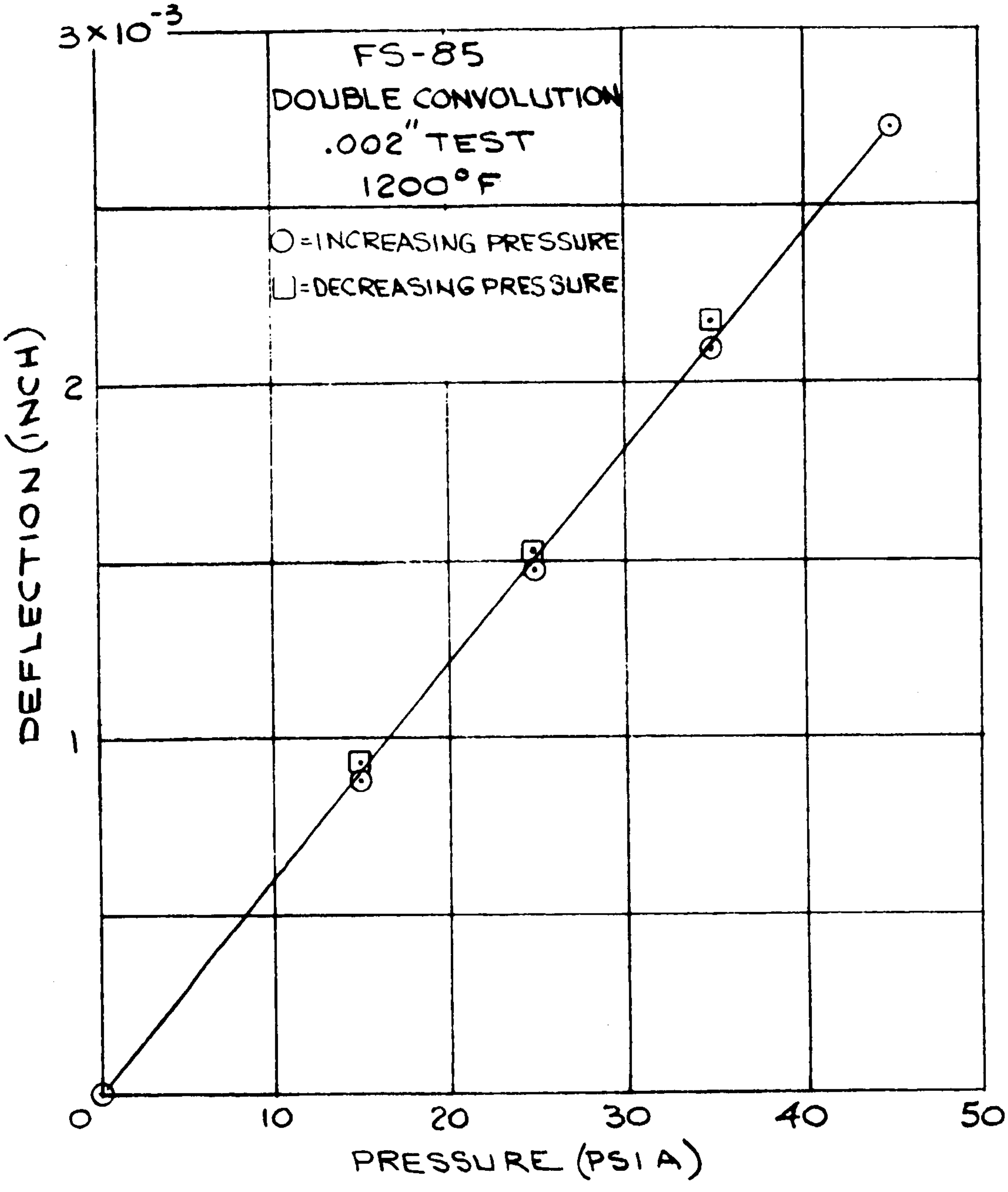

FIGURE 33

FS-85 PRESSURE-DEFLECTION, 1200°F

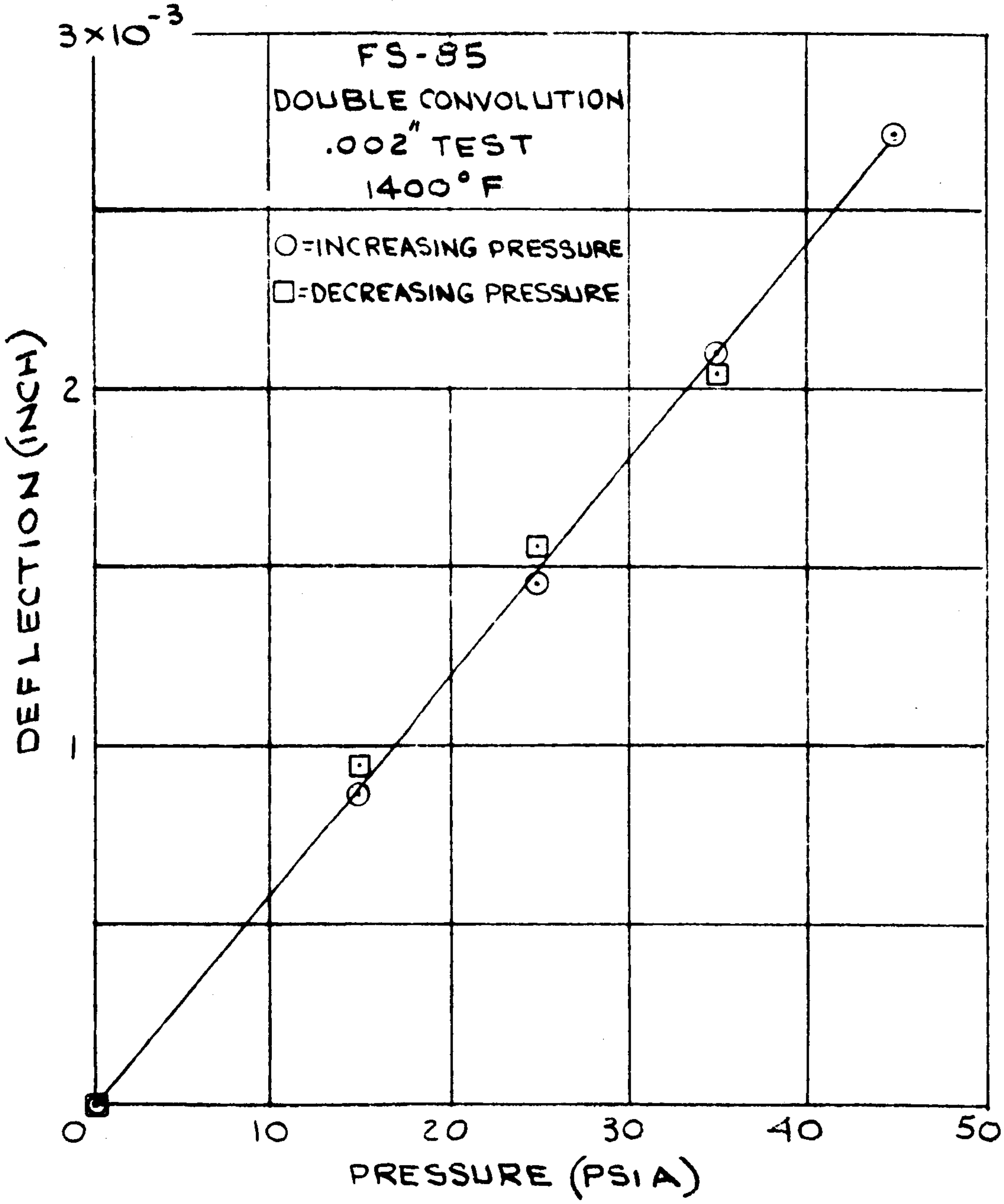

FIGURE 34

FS-85 PRESSURE-DEFLECTION, 1400°F

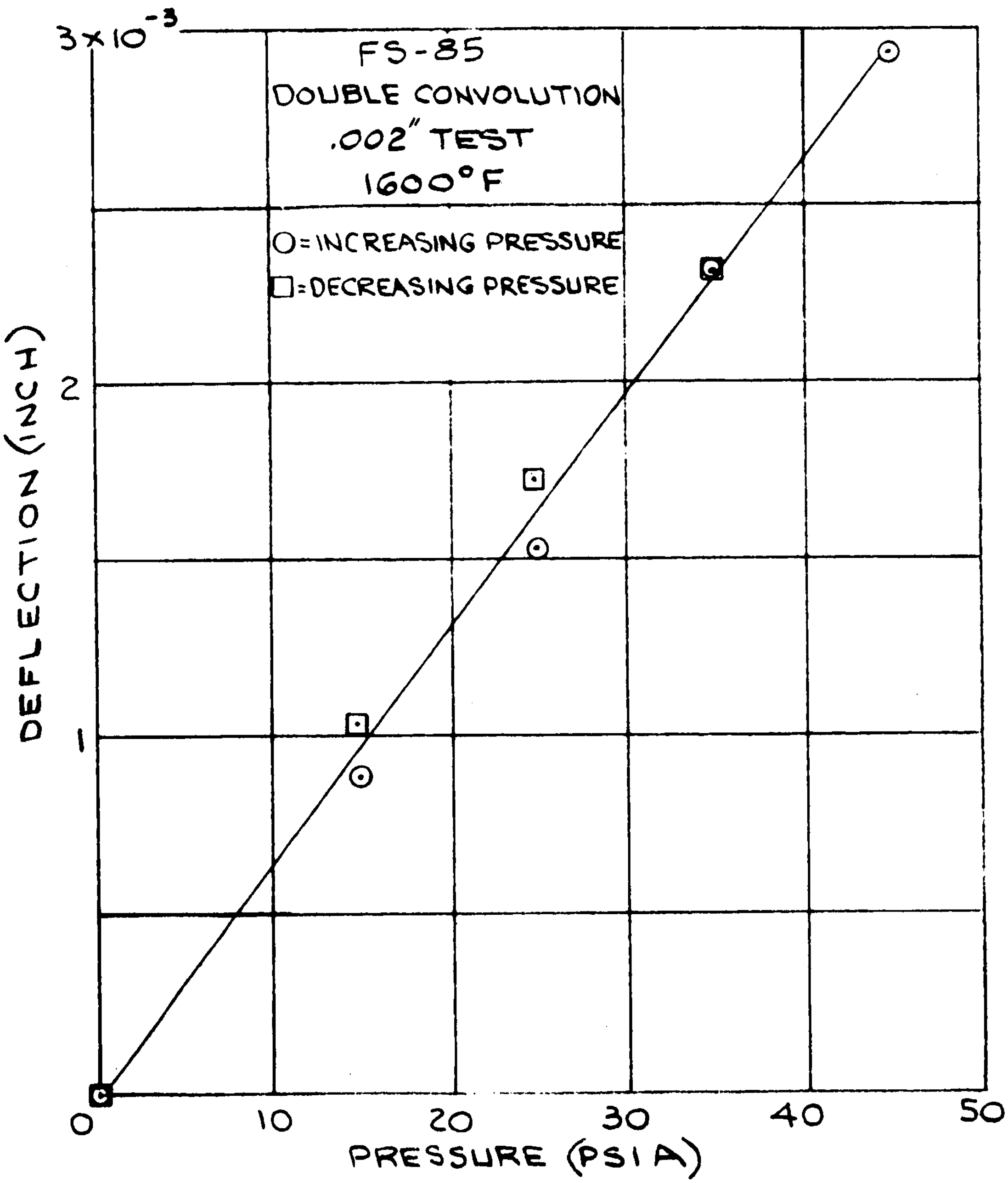

FIGURE 35

FS-85 PRESSURE-DEFLECTION, 1600°F

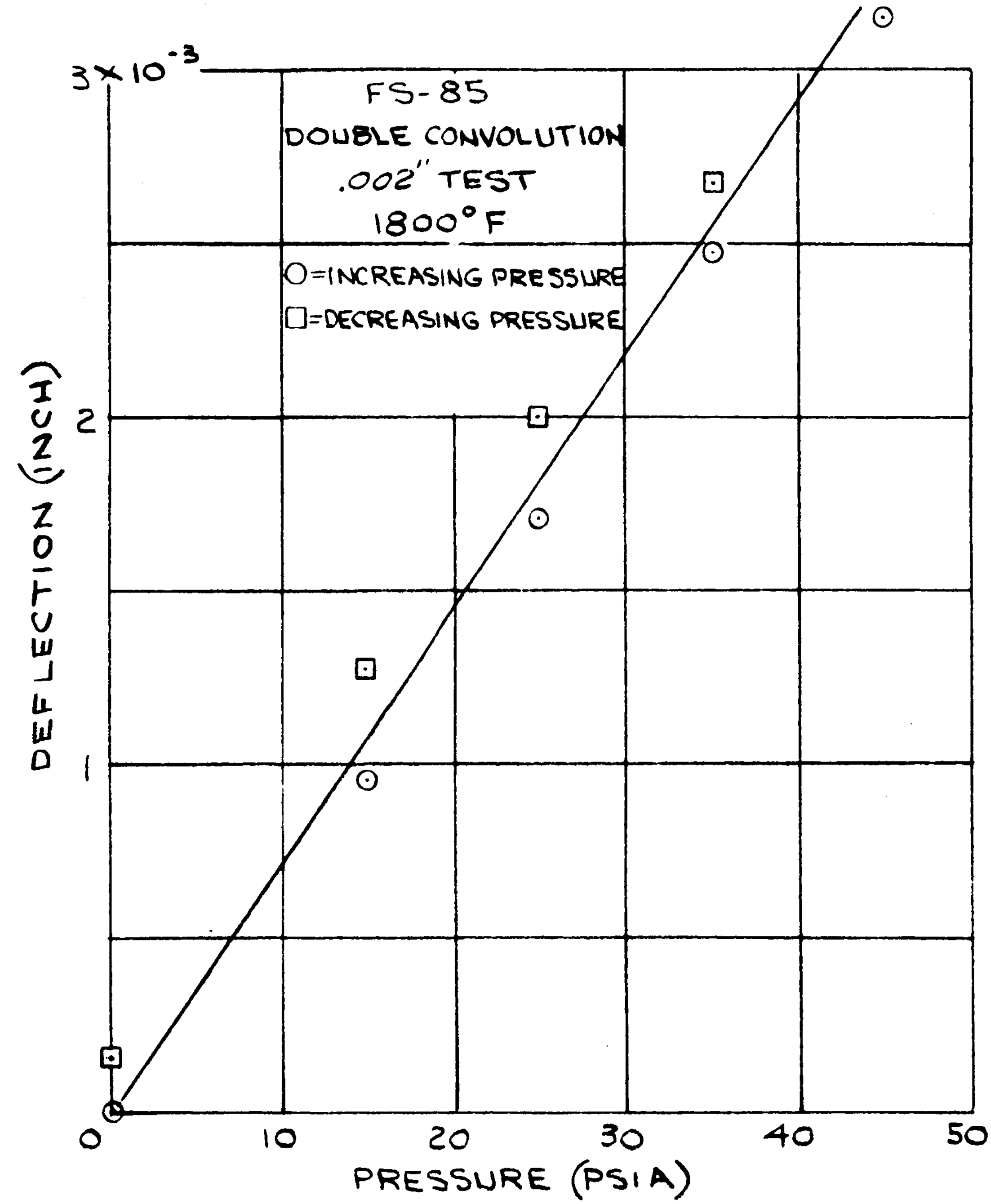

FIGURE 36

FS-85 PRESSURE-DEFLECTION, 1800°F

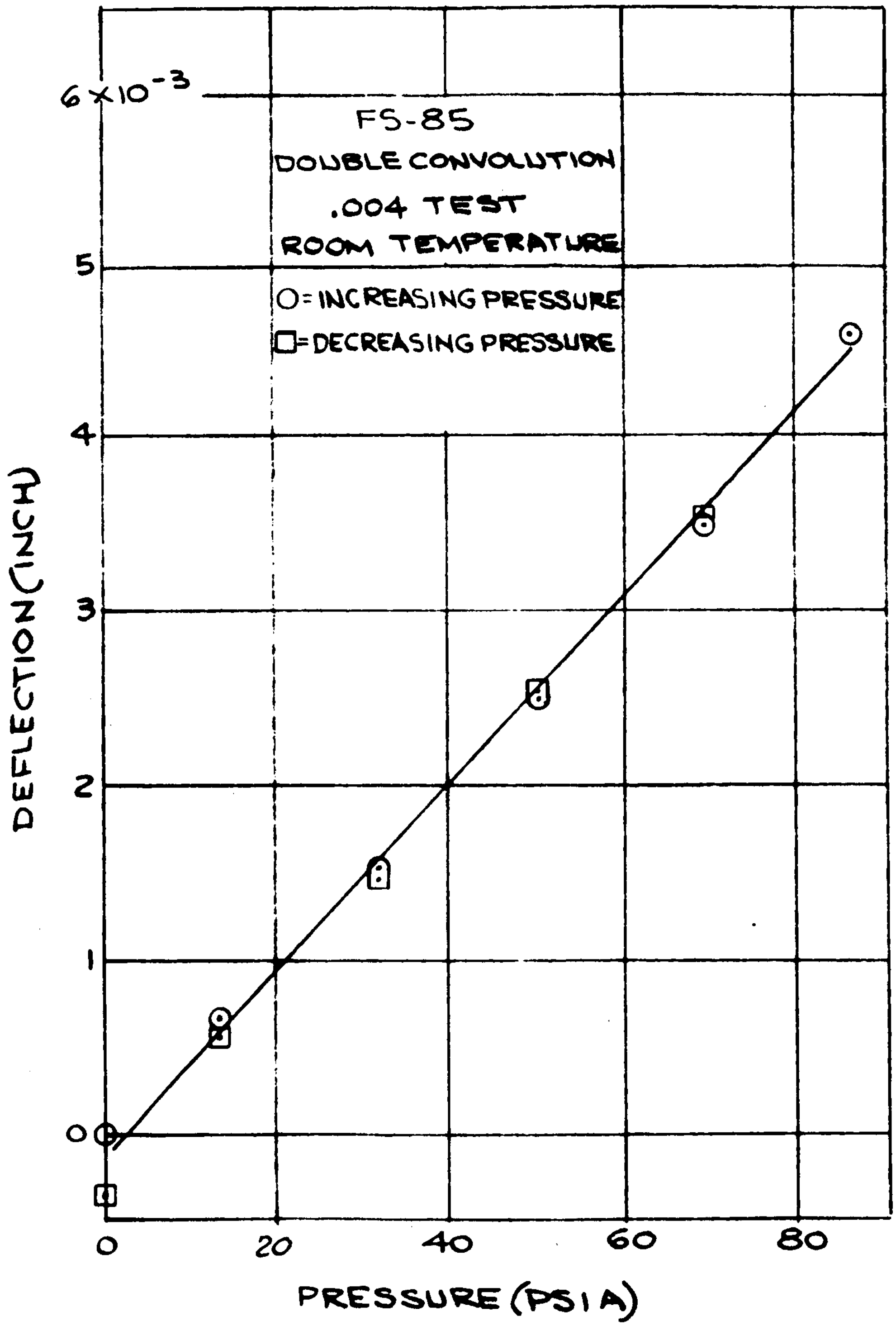

FIGURE 37

FS-85 PRESSURE-DEFLECTION, ROOM TEMPERATURE

BETHEL, CONNECTICUT

CONSOLIDATED CONTROLS CORPORATION

TEL: DANBURY 743-6721

June 4, 1965

National Aeronautics & Space Administration
Scientific & Technical Information Facility
P. O. Box 5700
Bethesda, Maryland 20014

Attention: NASA Representative

Subject: Transmittal of Fourth Quarterly Report

Dear Sir:

In accordance with our contract requirements we are hereby transmitting quarterly report for Contract NAS 3-4170.

To assure us that you have received your report would you kindly sign this letter below.

Very truly yours,

CONSOLIDATED CONTROLS CORPORATION

R. E. Engdahl
Project Manager

/sl

Please sign and return to CCC. Thank you.

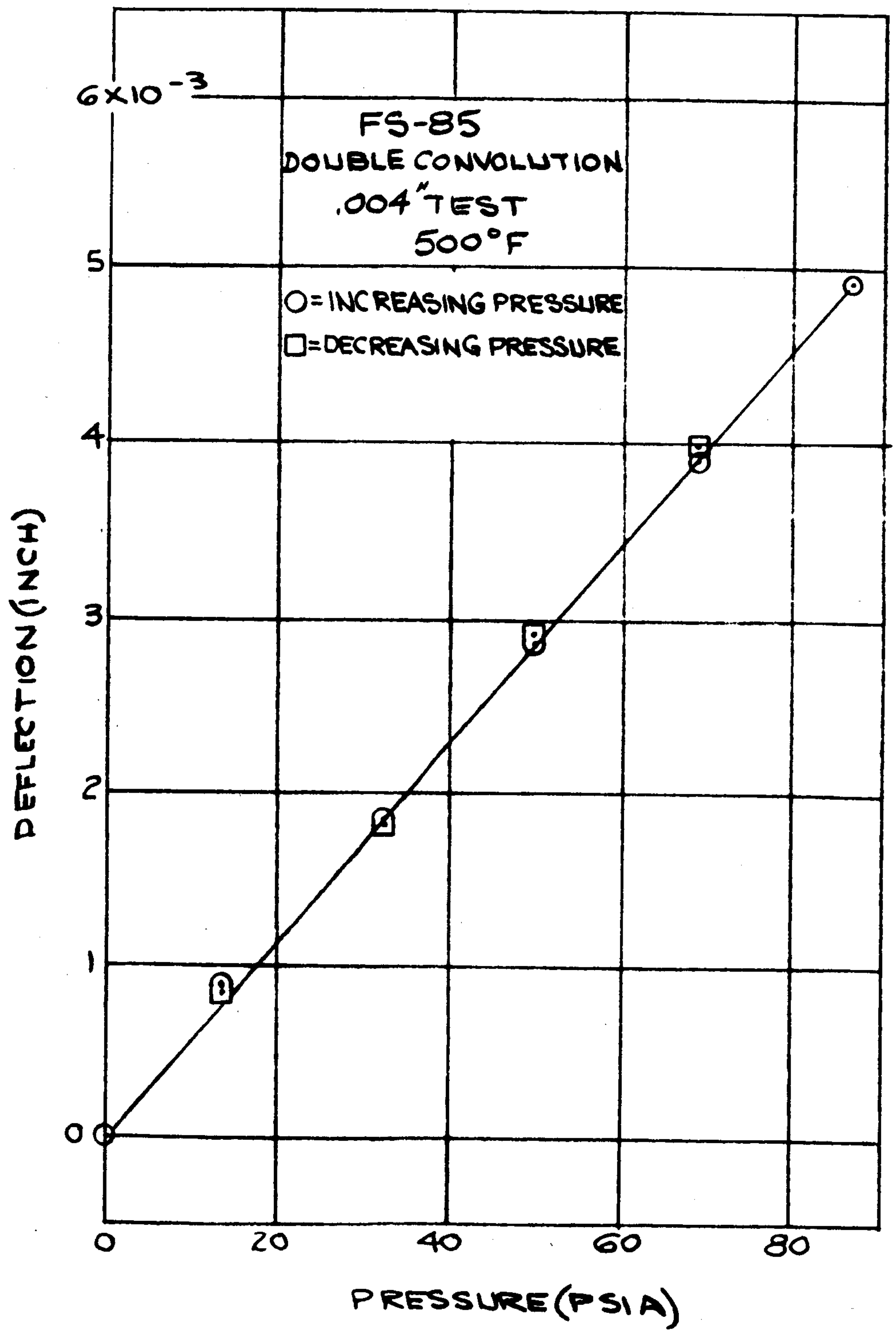

FIGURE 38

FS-85 PRESSURE-DEFLECTION, 500°F

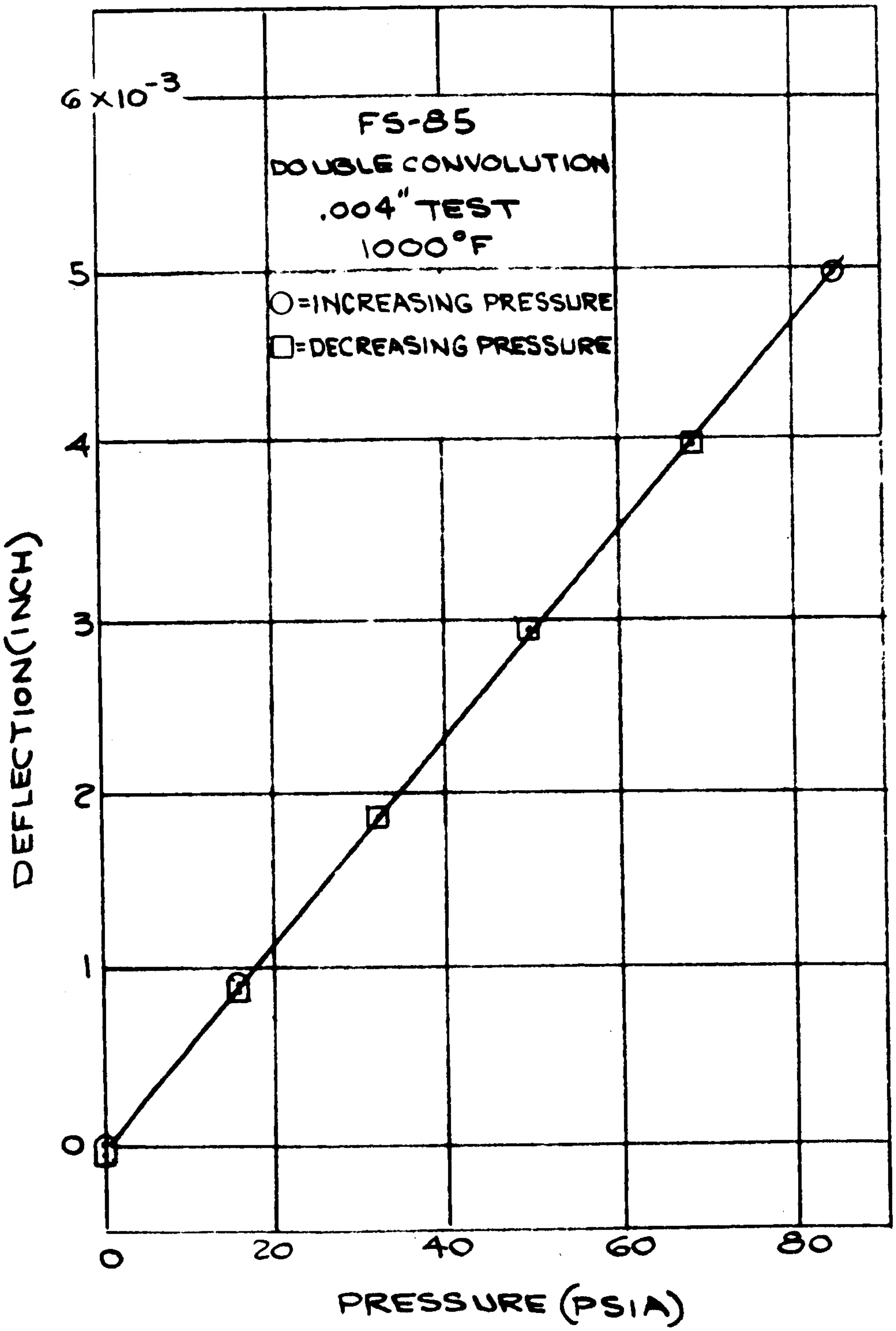

FIGURE 39

FS-85 PRESSURE-DEFLECTION, 1000°F

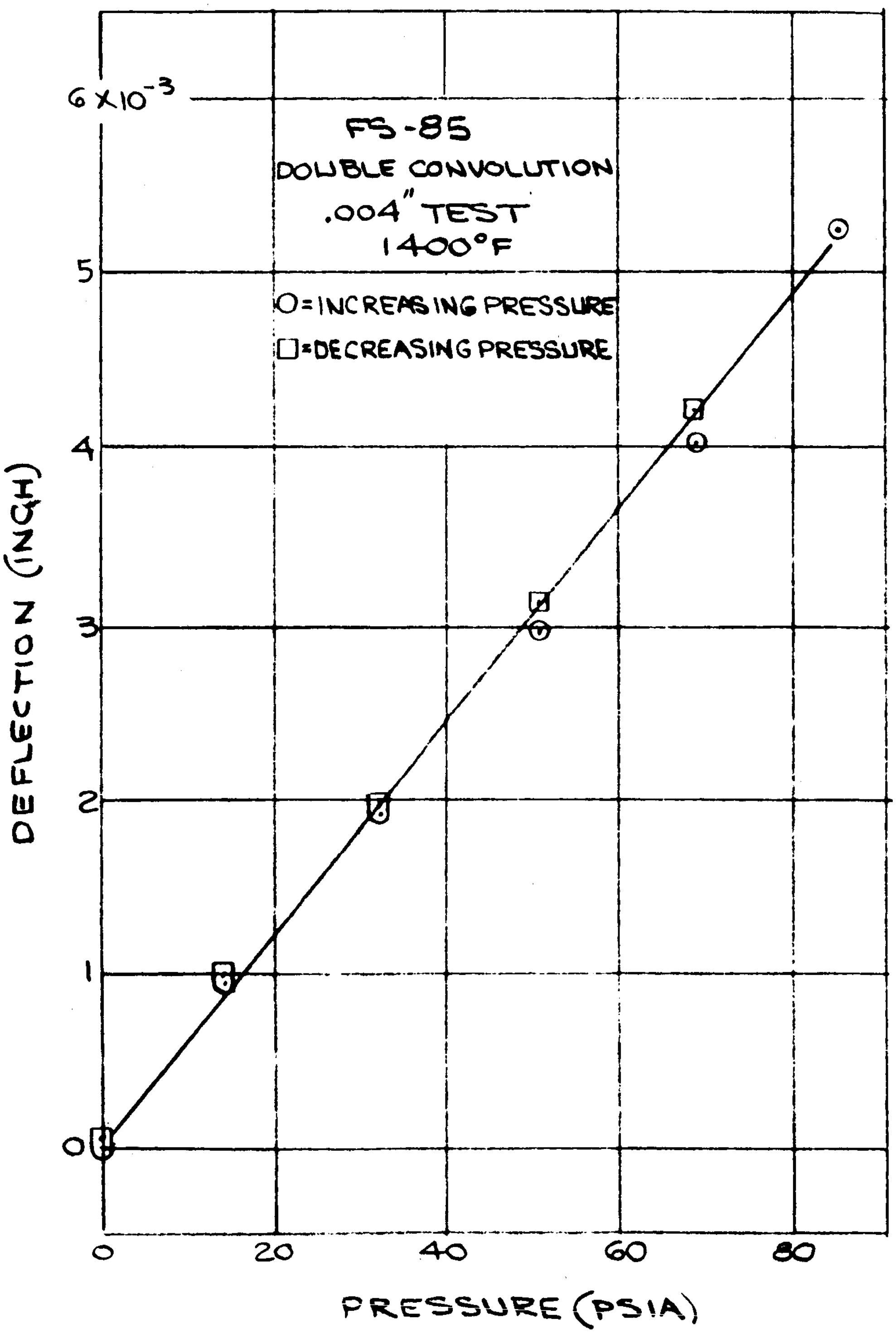

FIGURE 40

FS-85 PRESSURE-DEFLECTION, 1400°F

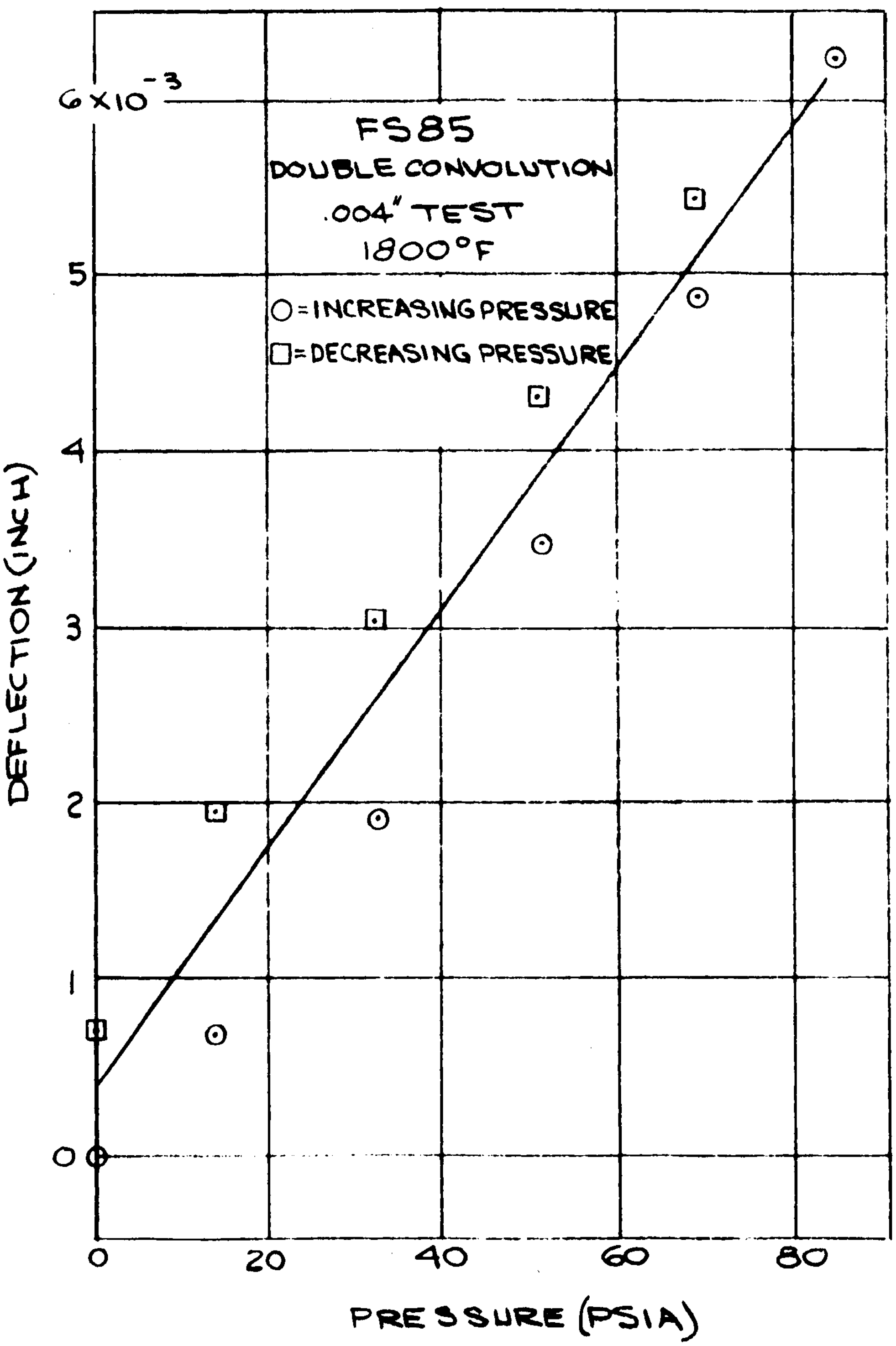

FIGURE 41

FS-85 PRESSURE-DEFLECTION, 1800°F

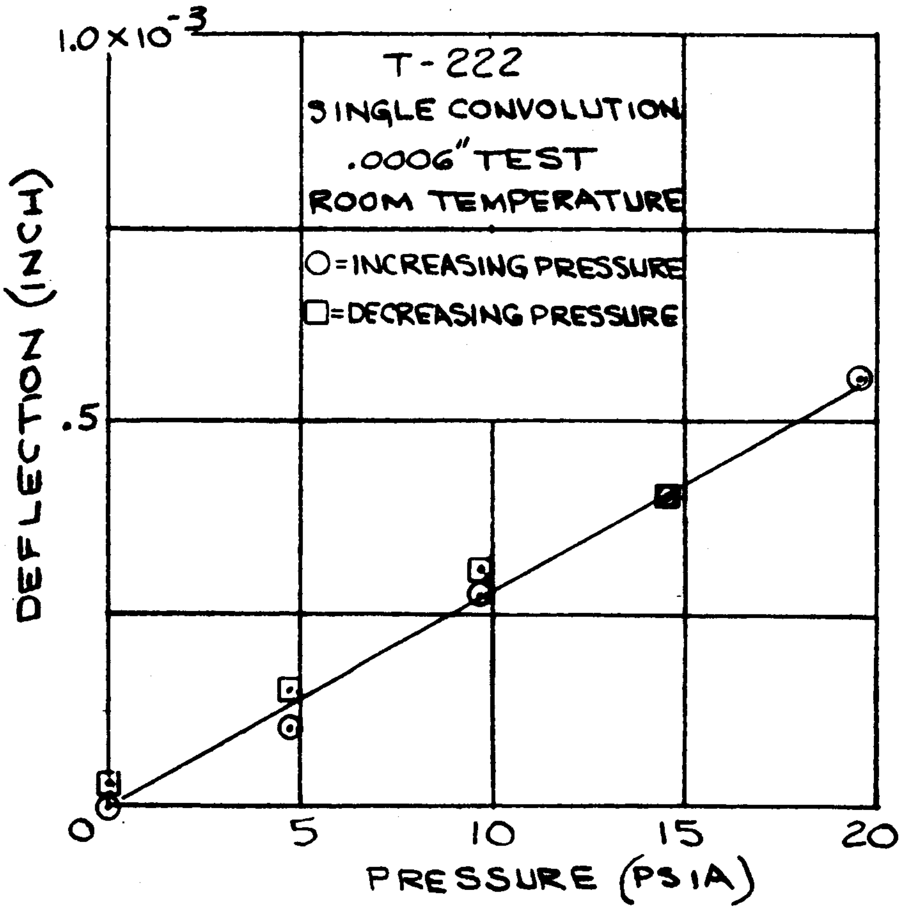

FIGURE 42

T-222 PRESSURE-DEFLECTION, ROOM TEMPERATURE

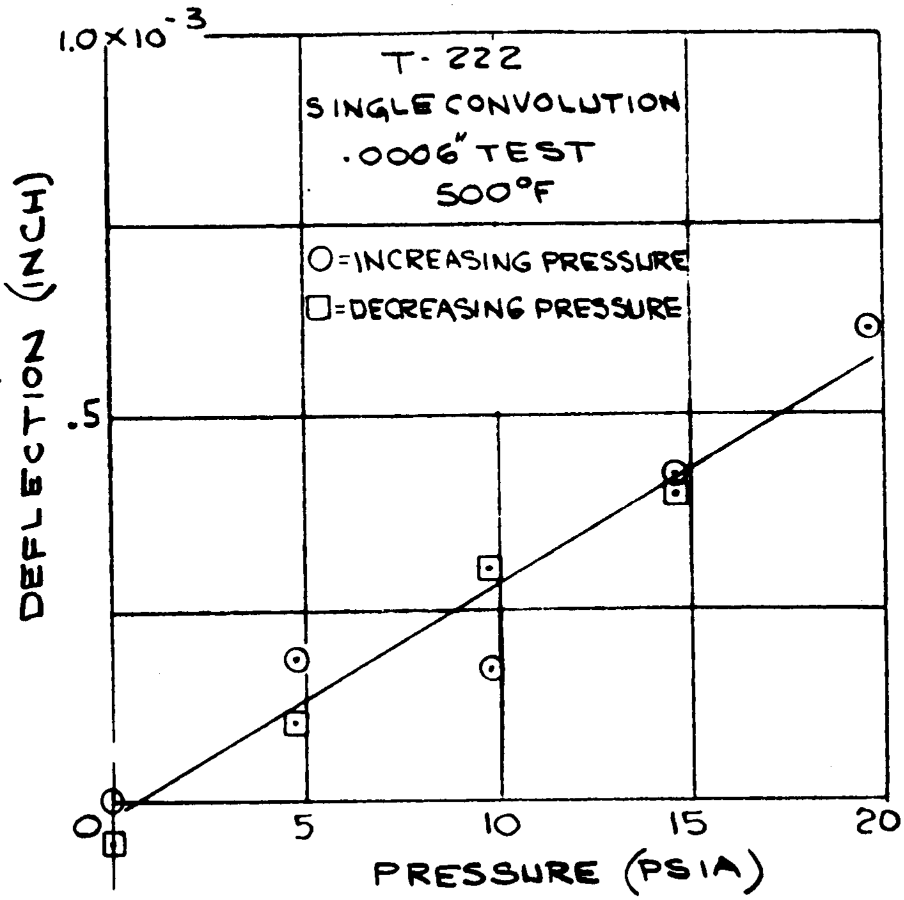

FIGURE 43

T-222 PRESSURE-DEFLECTION, 500°F

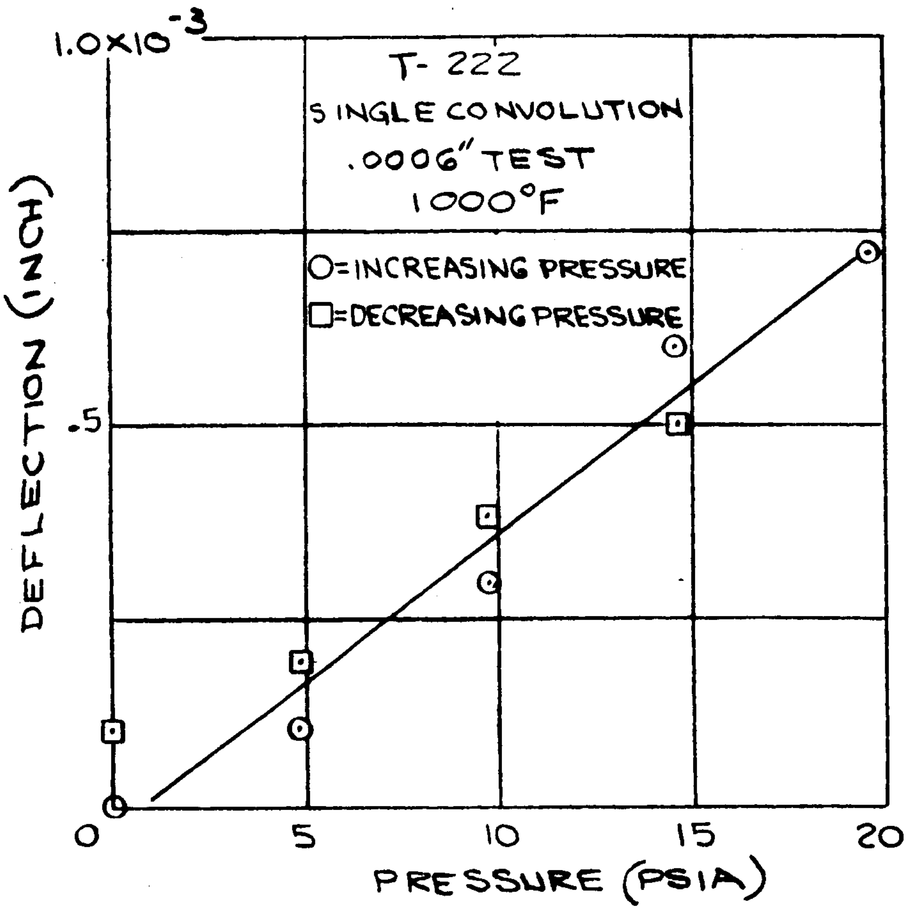

FIGURE 44

T-222 PRESSURE-DEFLECTION, 1000°F

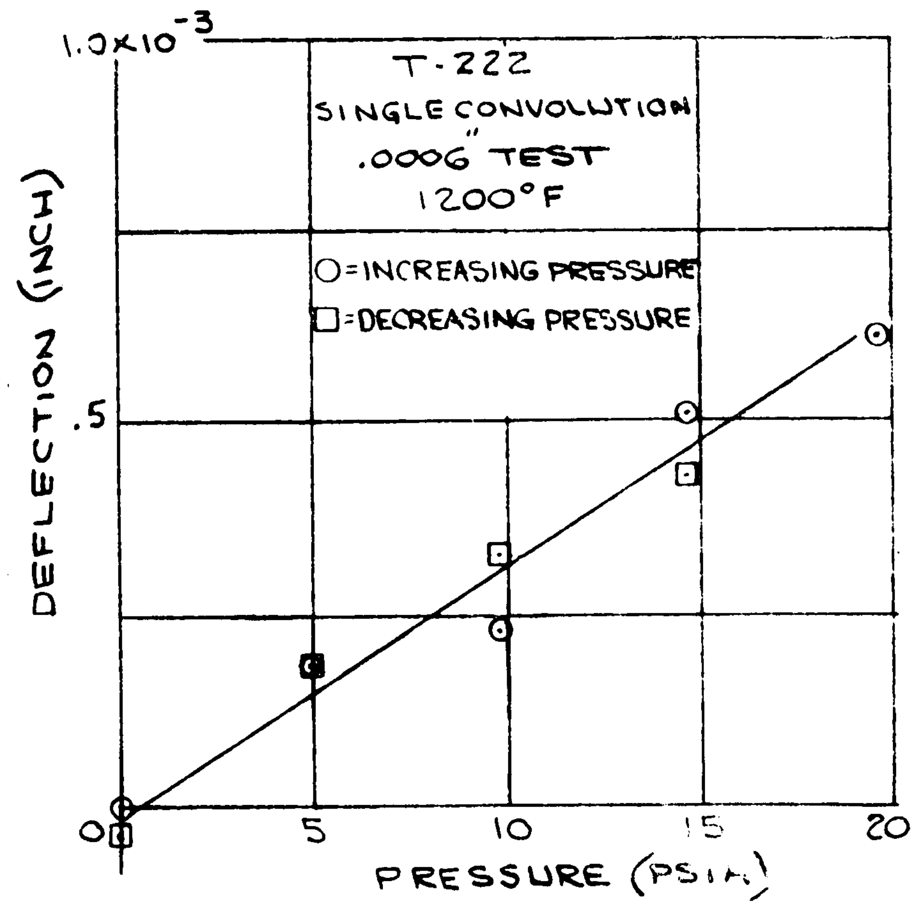

FIGURE 45

T-222 PRESSURE-DEFLECTION, 1200°F

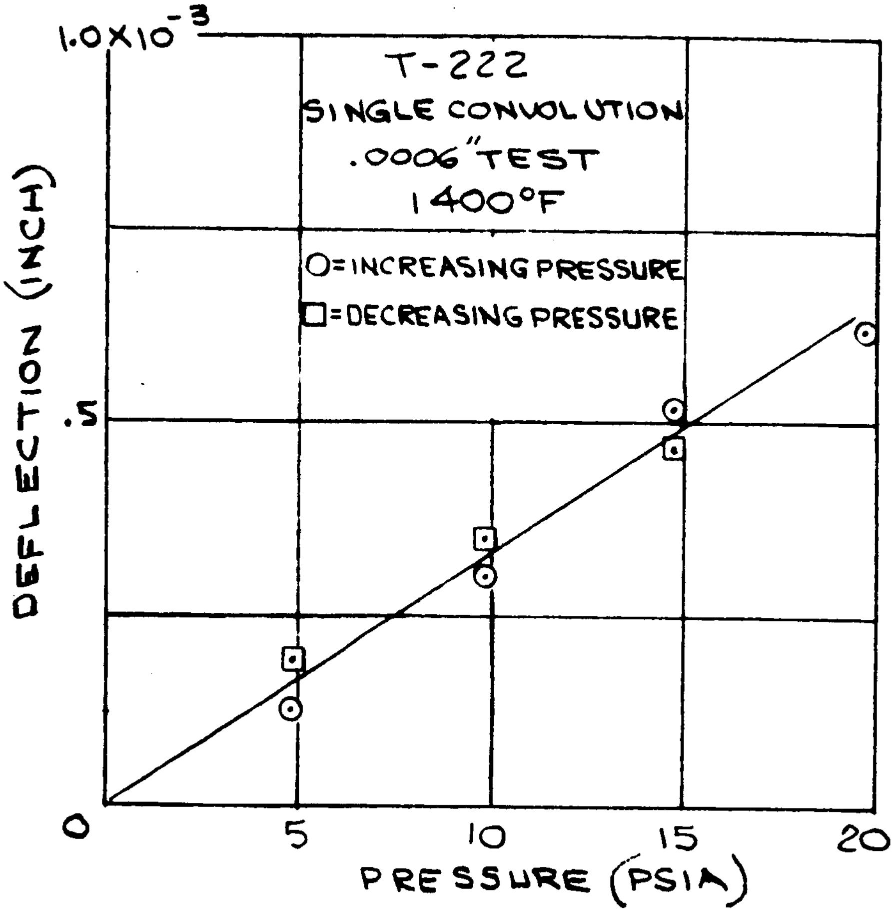

FIGURE 46

T-222 PRESSURE-DEFLECTION, 1400°F

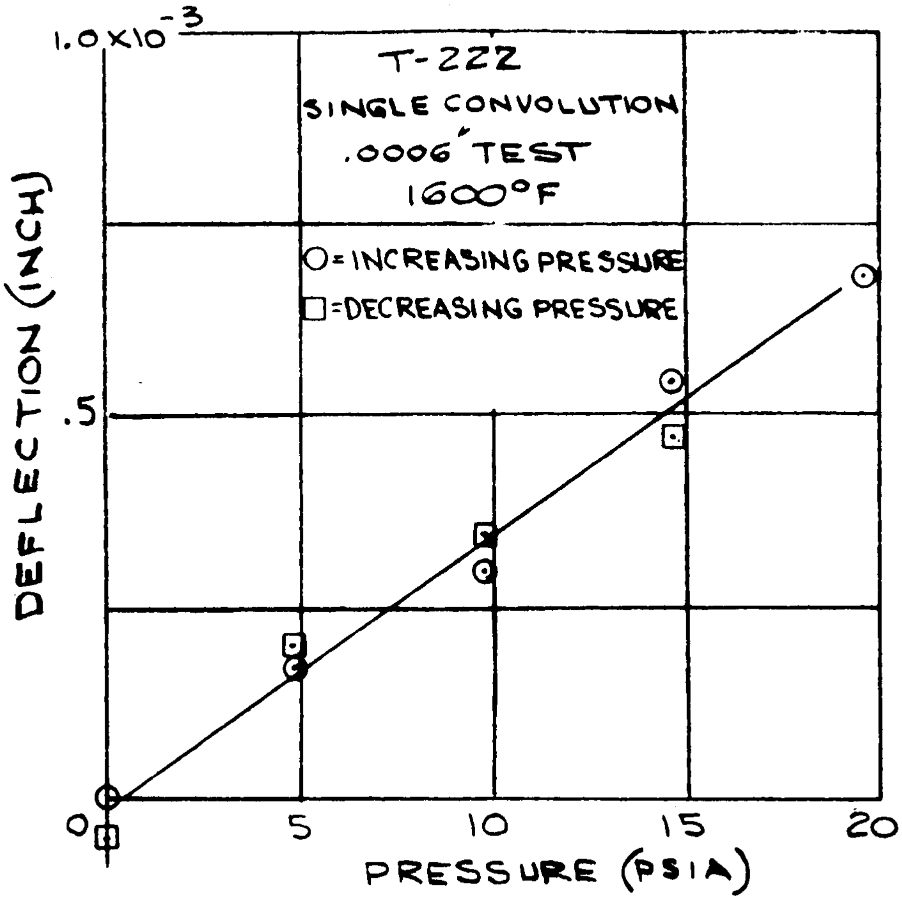

FIGURE 47

T-222 PRESSURE-DEFLECTION, 1600°F

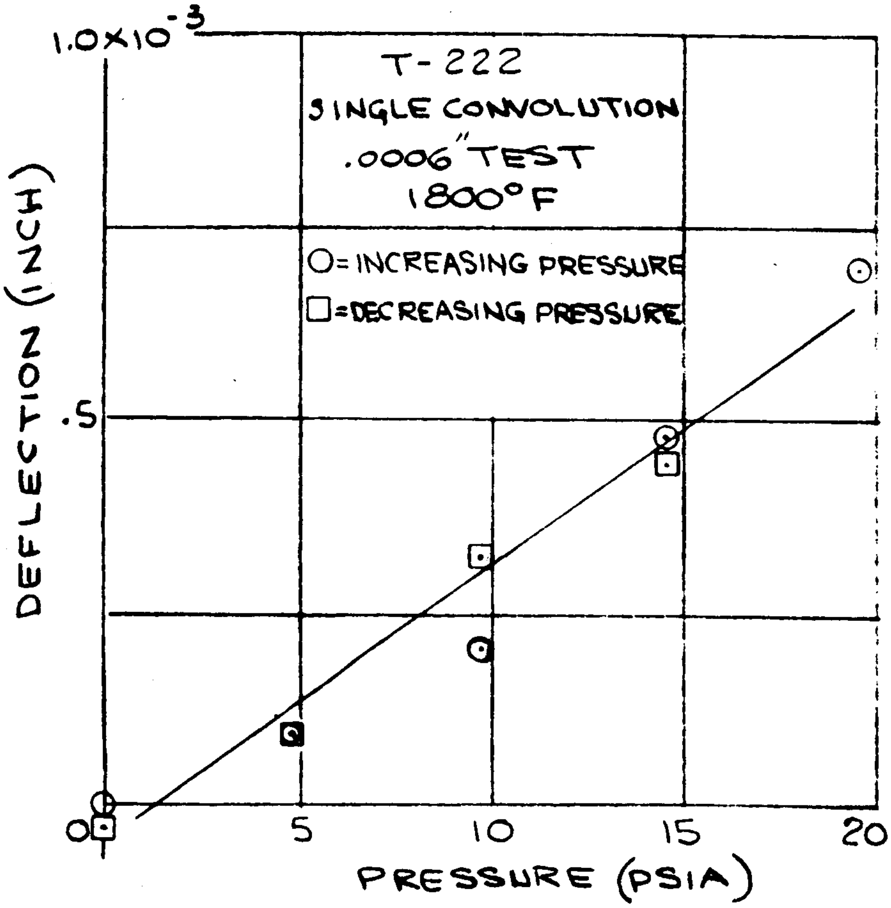

FIGURE 48

T-222 PRESSURE-DEFLECTION, 1800°F

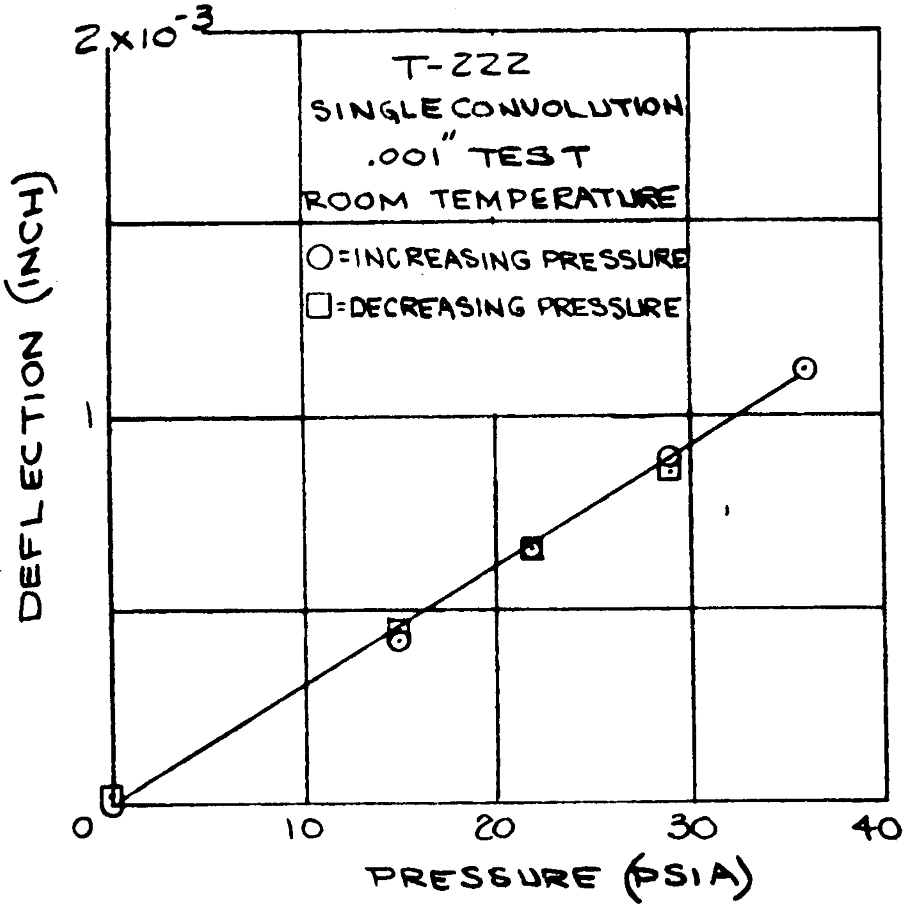

FIGURE 49

T-222 PRESSURE-DEFLECTION, ROOM TEMPERATURE

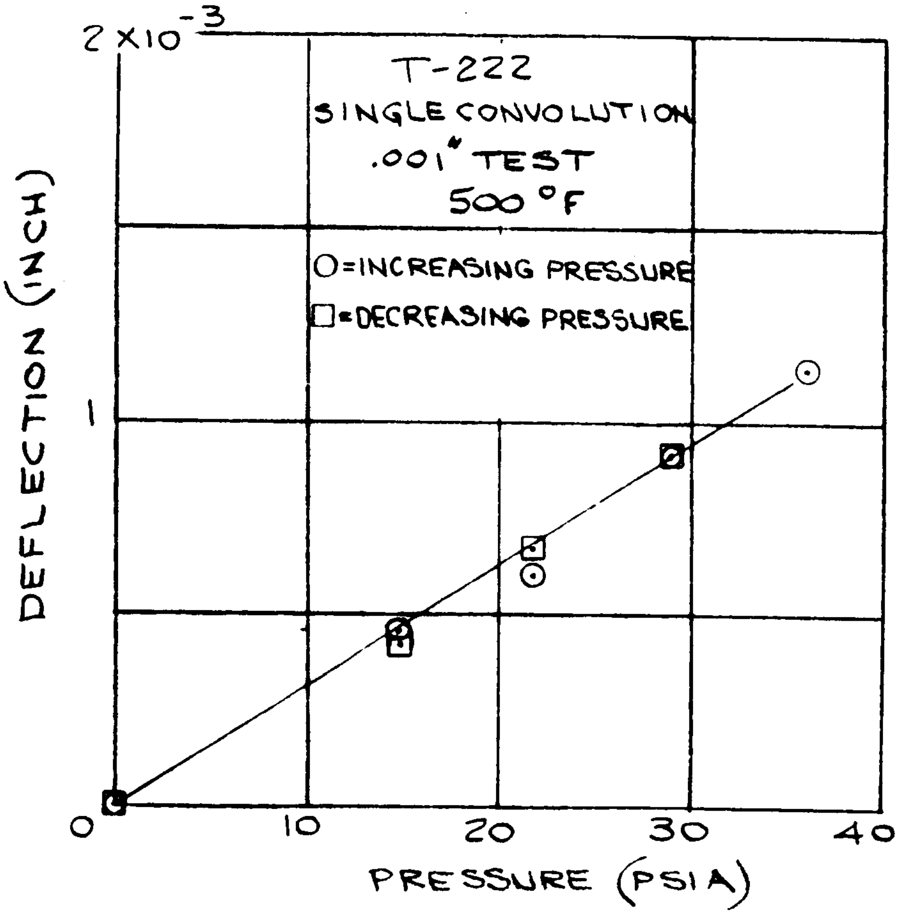

FIGURE 50

T-222 PRESSURE-DEFLECTION, 500°F

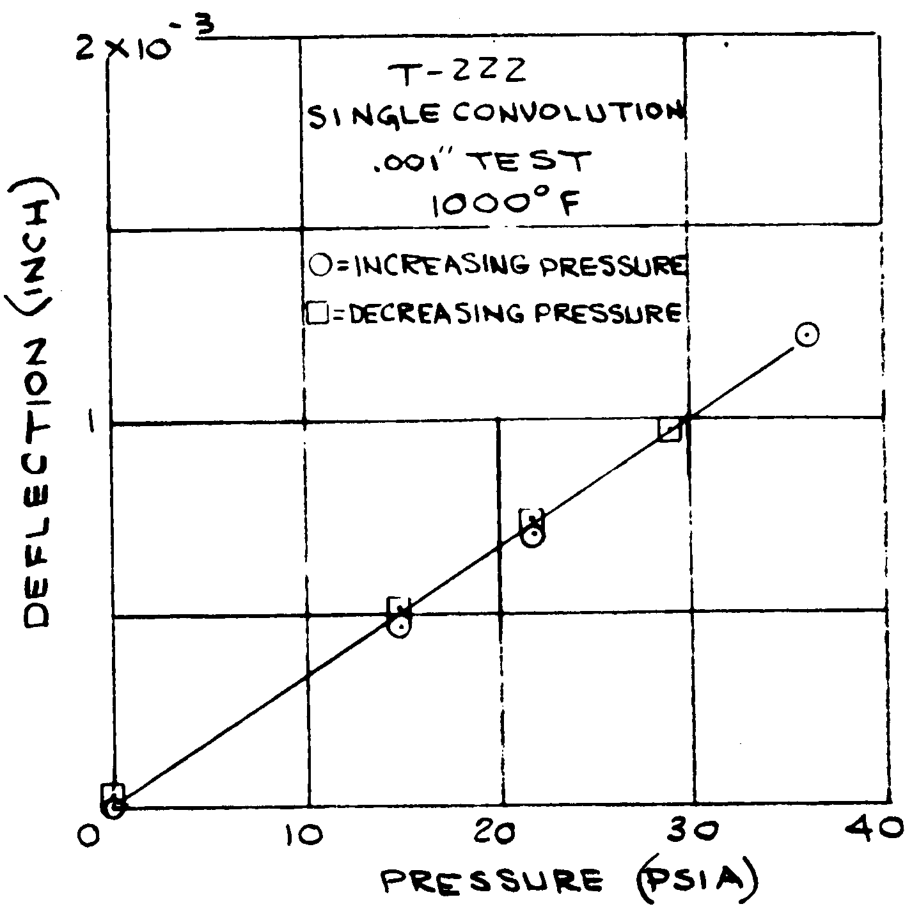

FIGURE 51

T-222 PRESSURE-DEFLECTION, 1000°F

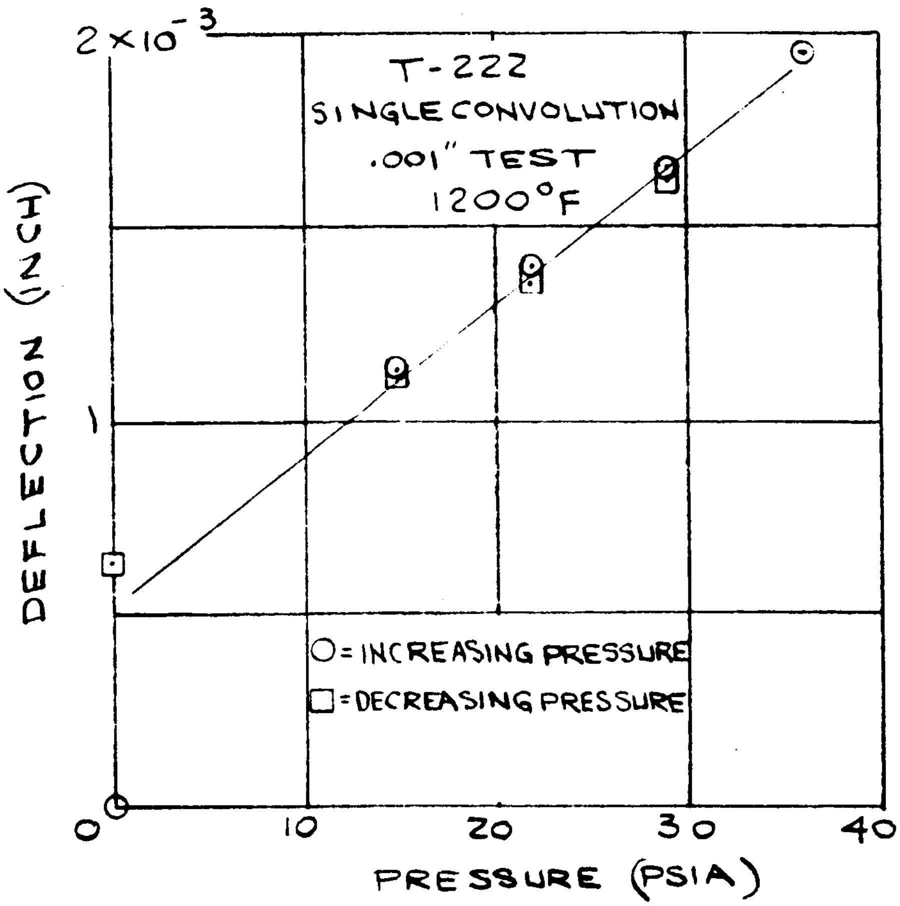

FIGURE 52

T-222 PRESSURE-DEFLECTION, 1200°F

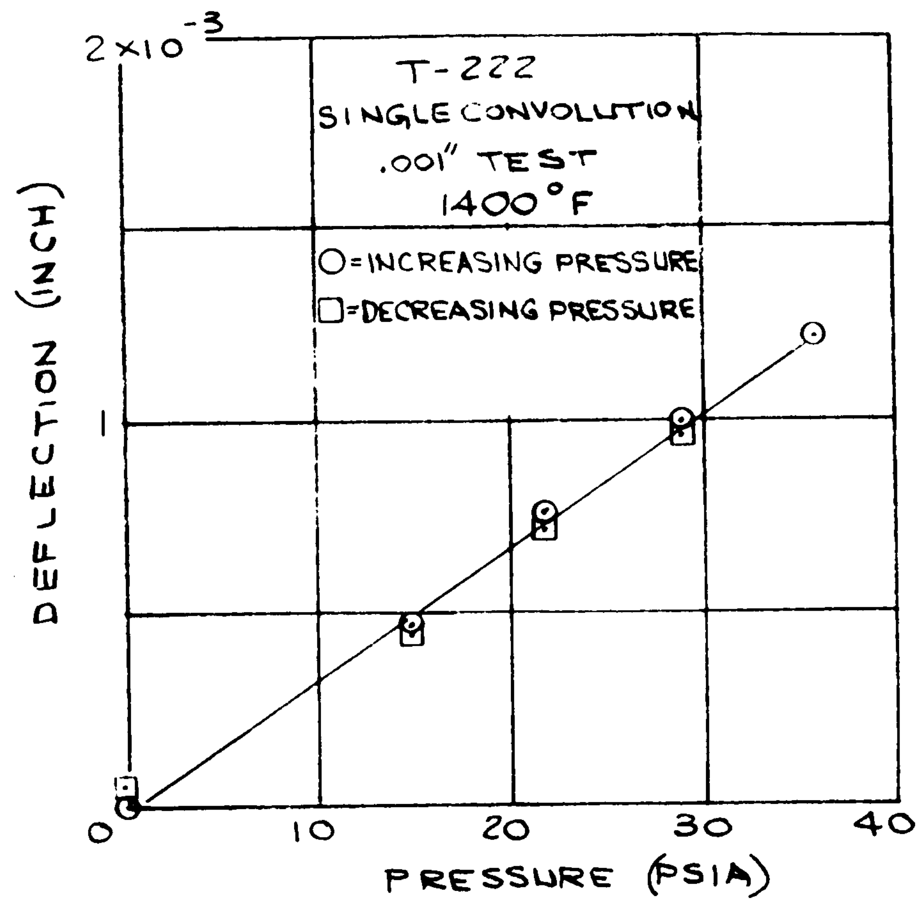

FIGURE 53

T-222 PRESSURE-DEFLECTION, 1400°F

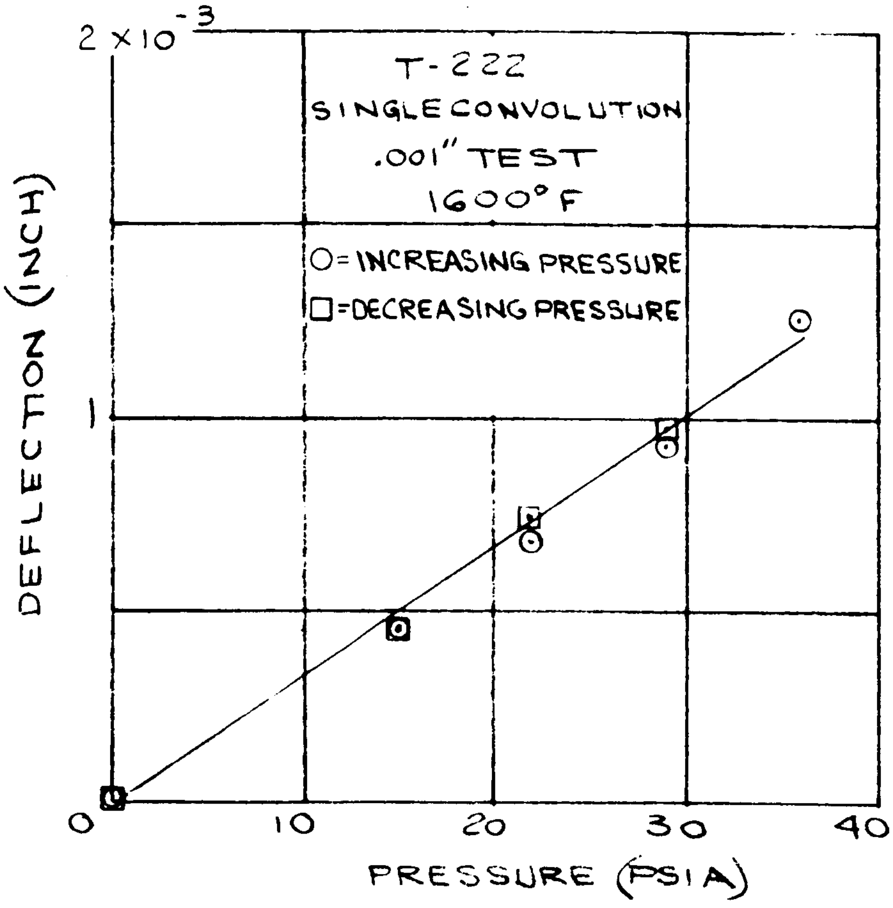

FIGURE 54

T-222 PRESSURE-DEFLECTION, 1600°F

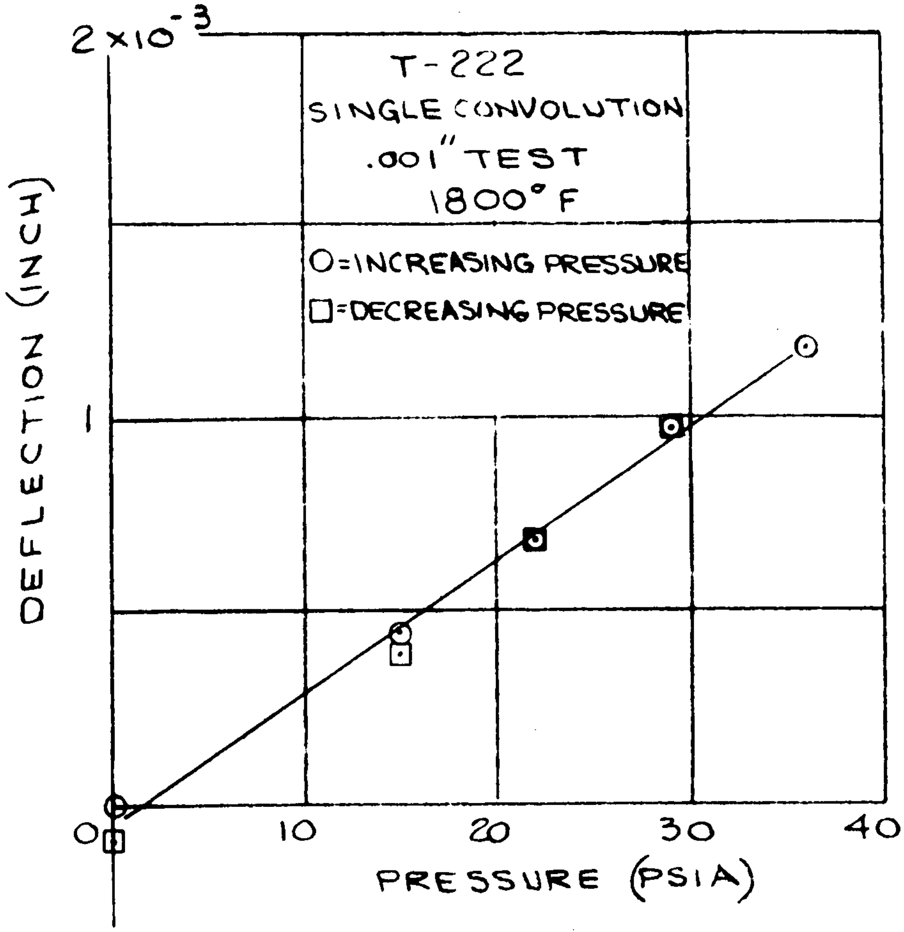

FIGURE 55

T-222 PRESSURE-DEFLECTION, 1800°F

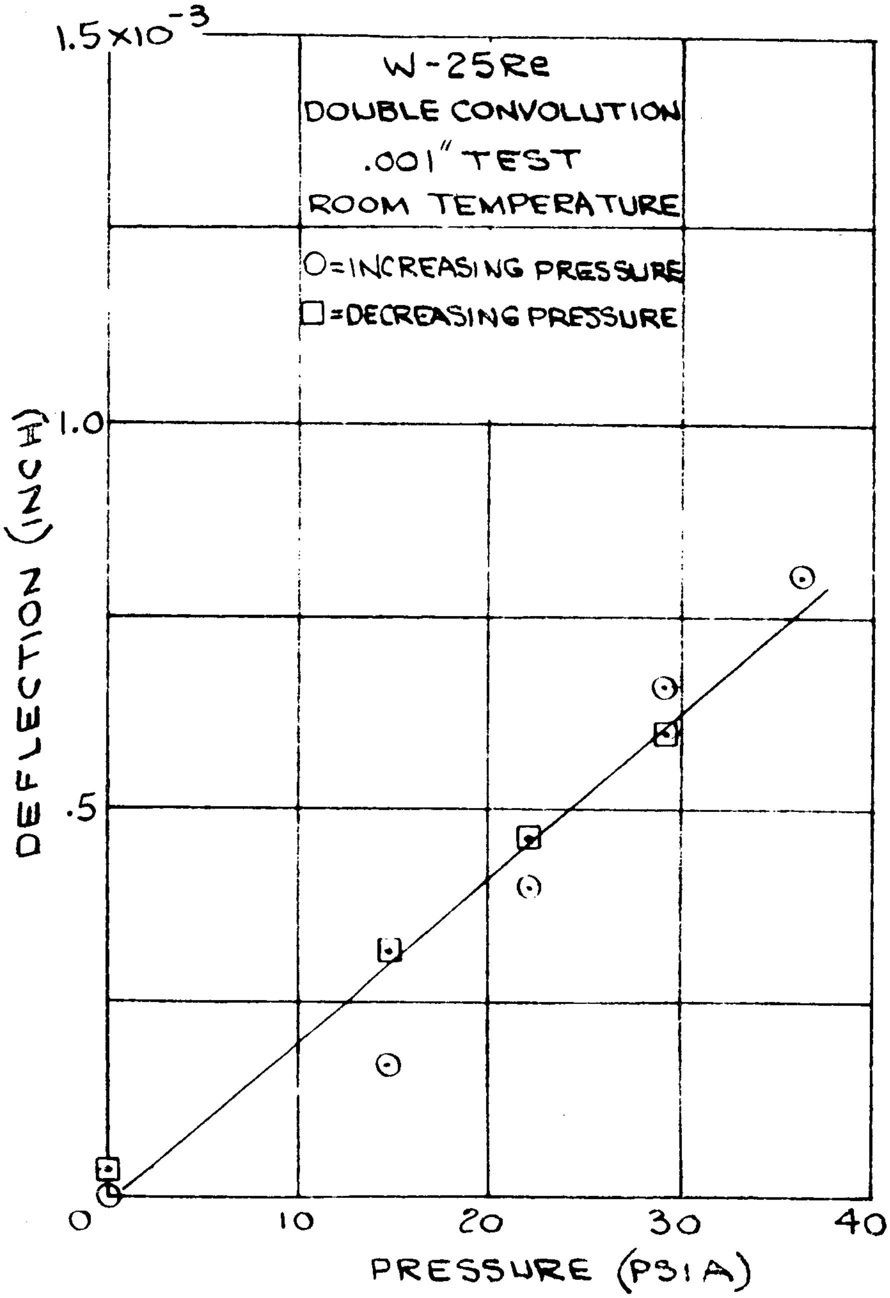

FIGURE 56

W-25Re PRESSURE-DEFLECTION, ROOM TEMPERATURE

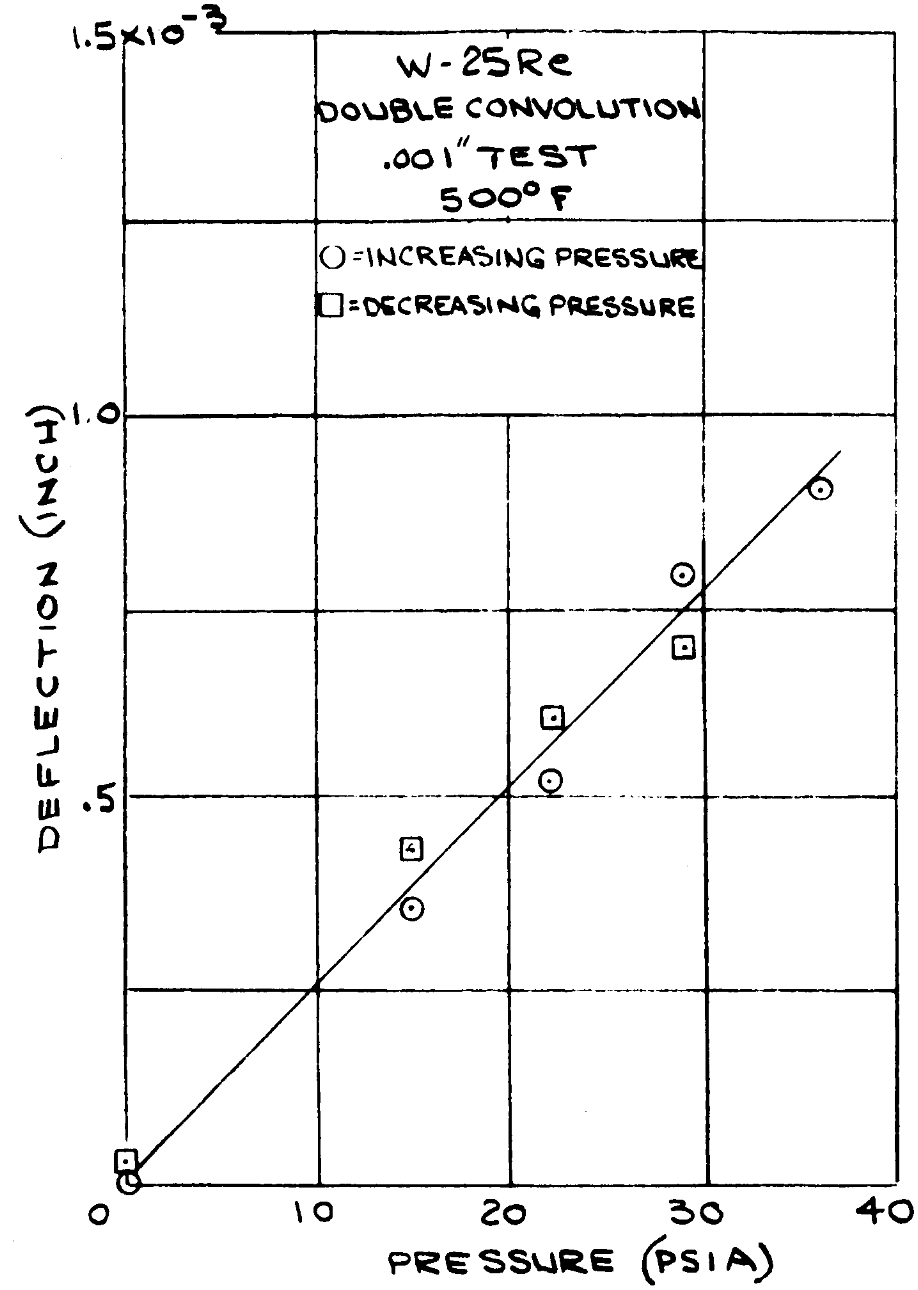

FIGURE 57

W-25Re PRESSURE-DEFLECTION, 500°F

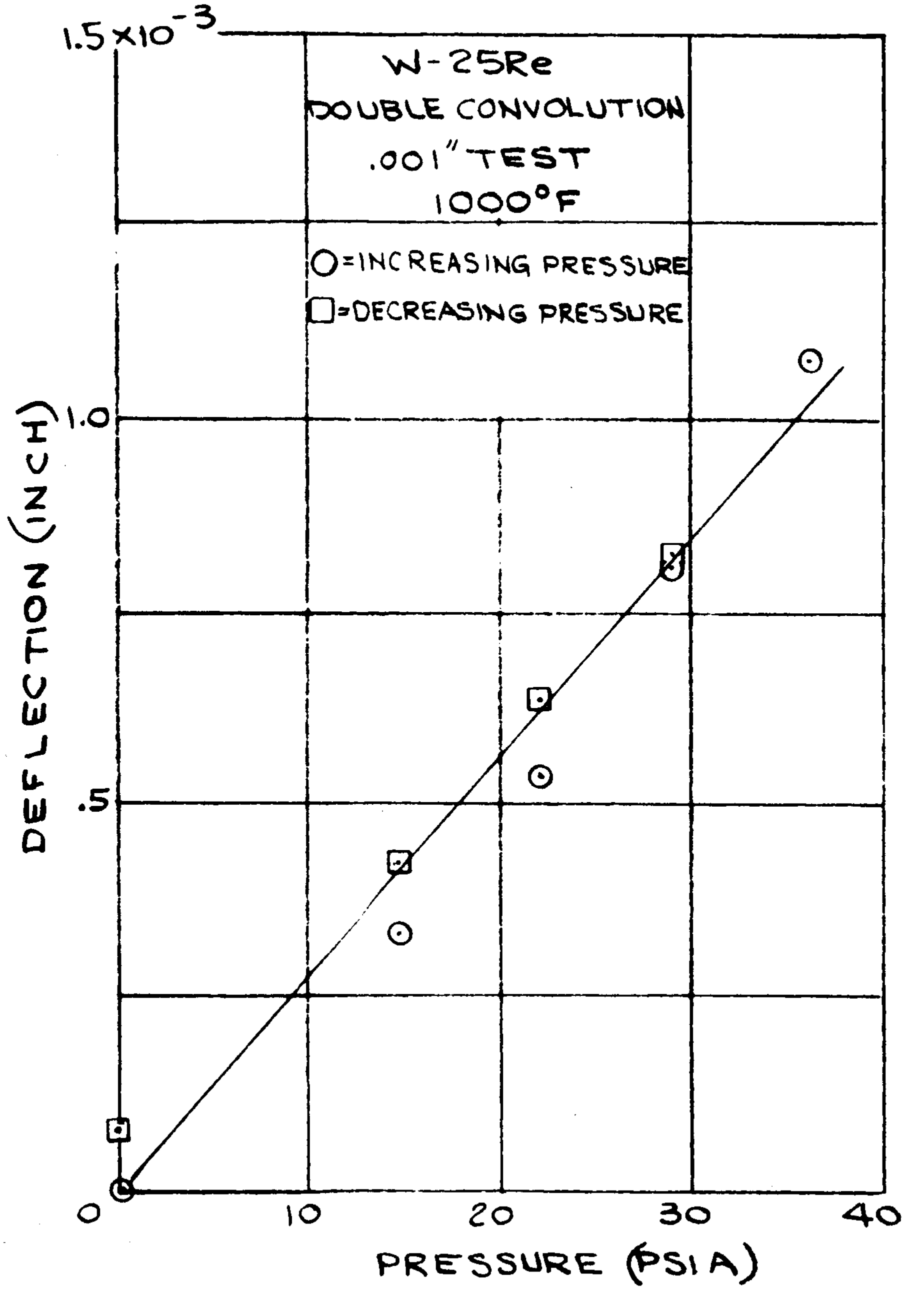

FIGURE 58

W-25Re PRESSURE-DEFLECTION, 1000°F

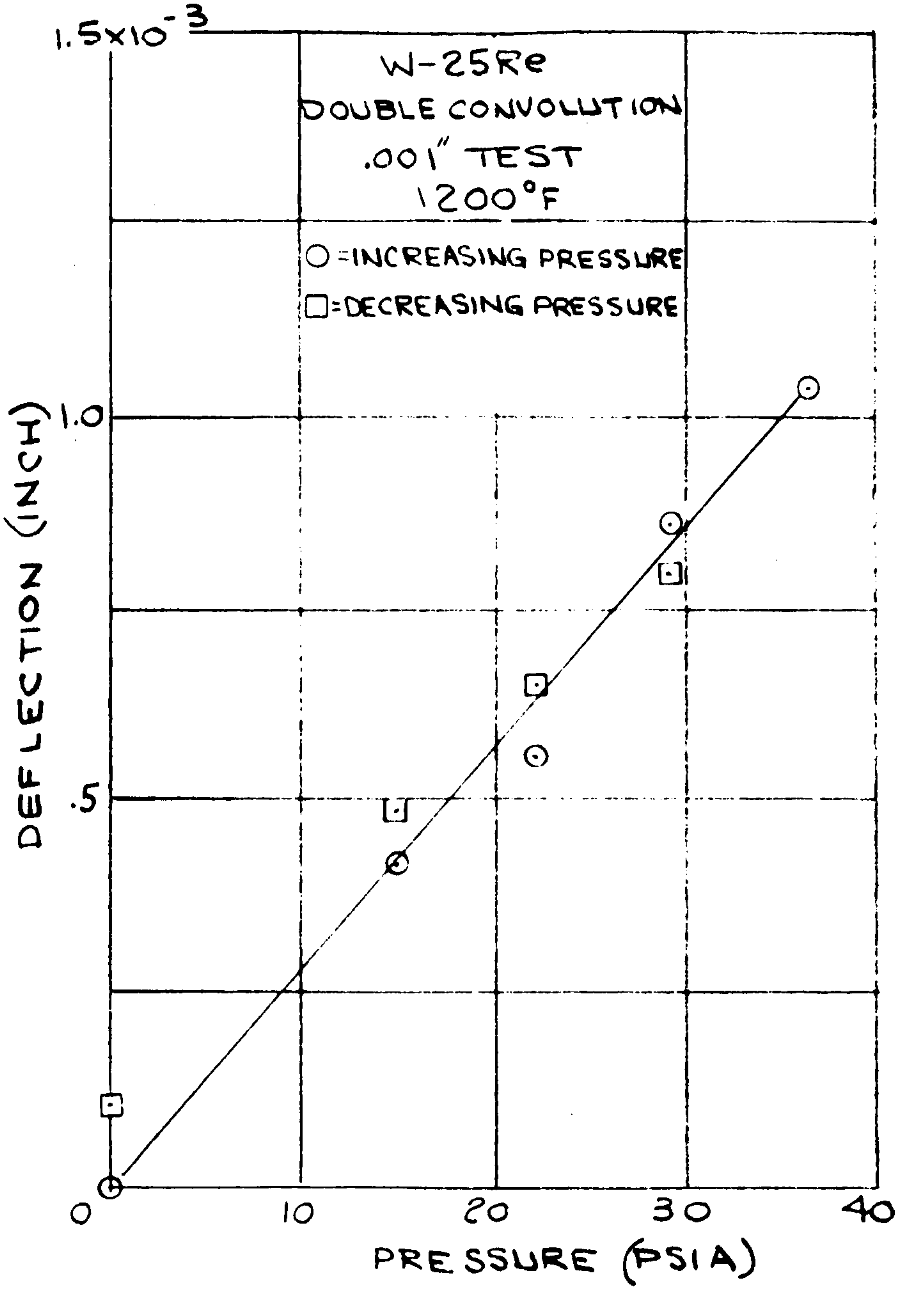

FIGURE 59

W-25Re PRESSURE-DEFLECTION, 1200°F

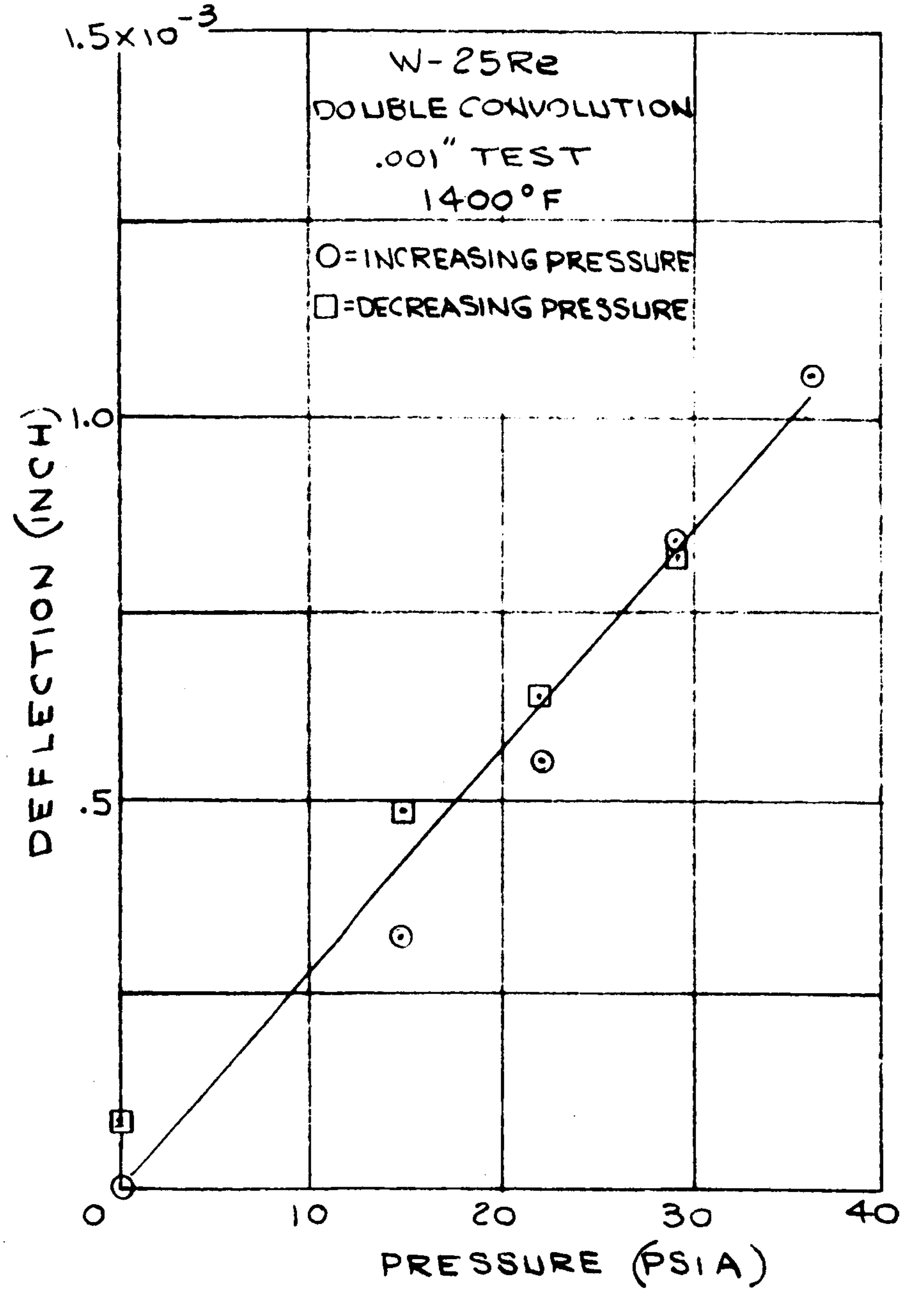

FIGURE 60

W-25Re PRESSURE-DEFLECTION, 1400°F

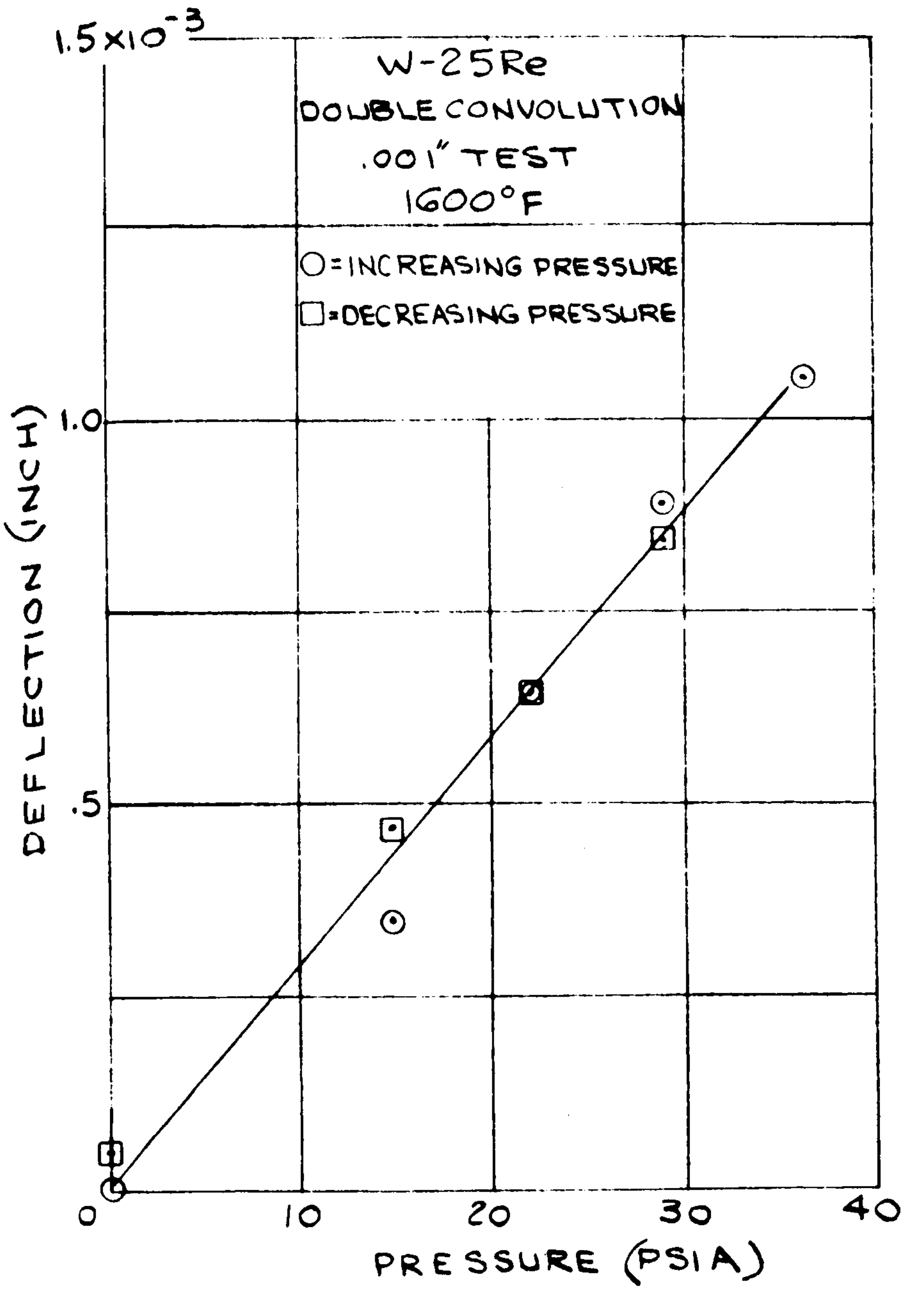

FIGURE 61

W-25Re PRESSURE-DEFLECTION, 1600°F

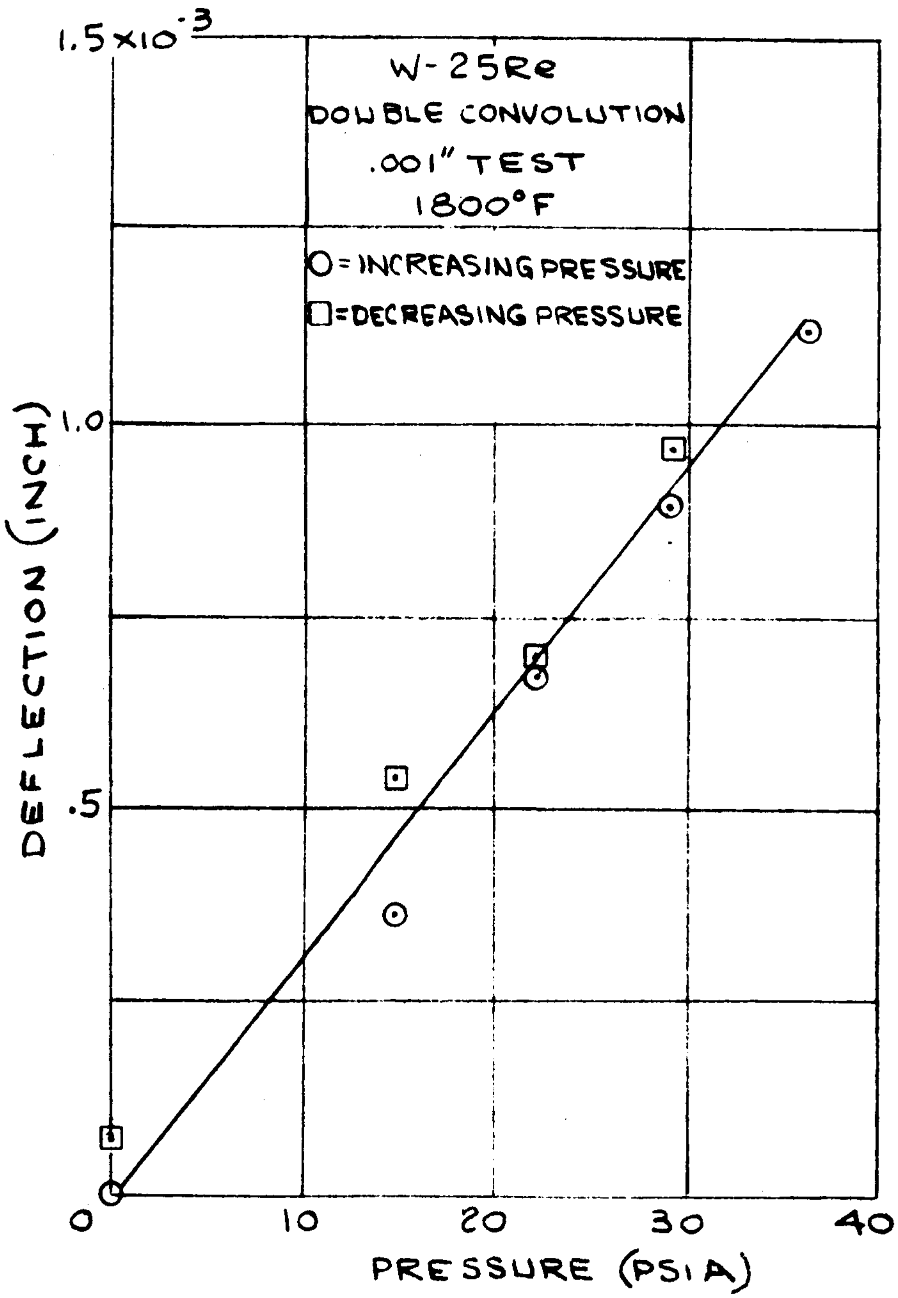

FIGURE 62

W-25Re PRESSURE-DEFLECTION, 1800°F

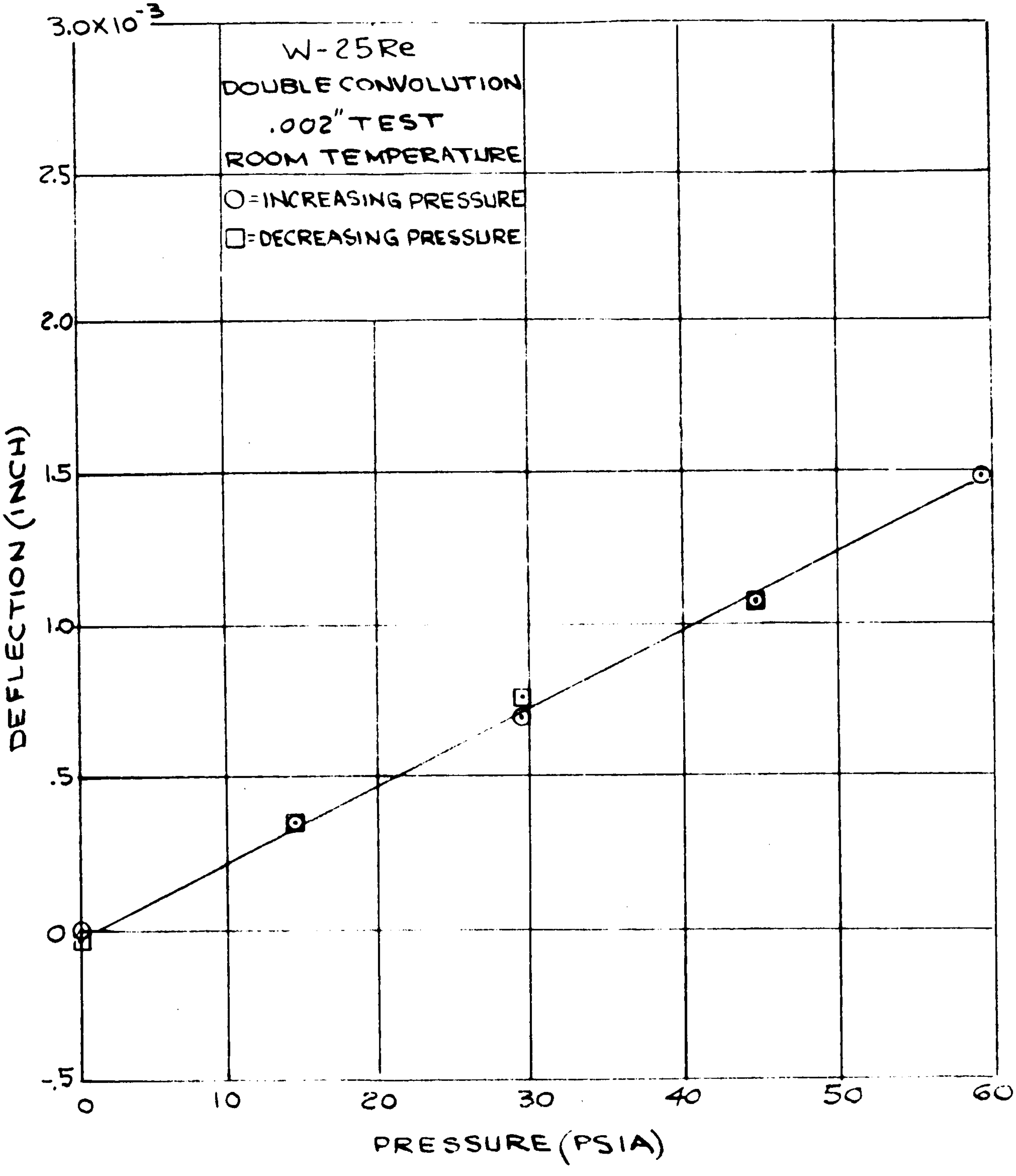

FIGURE 63

W-25Re PRESSURE-DEFLECTION, ROOM TEMPERATURE

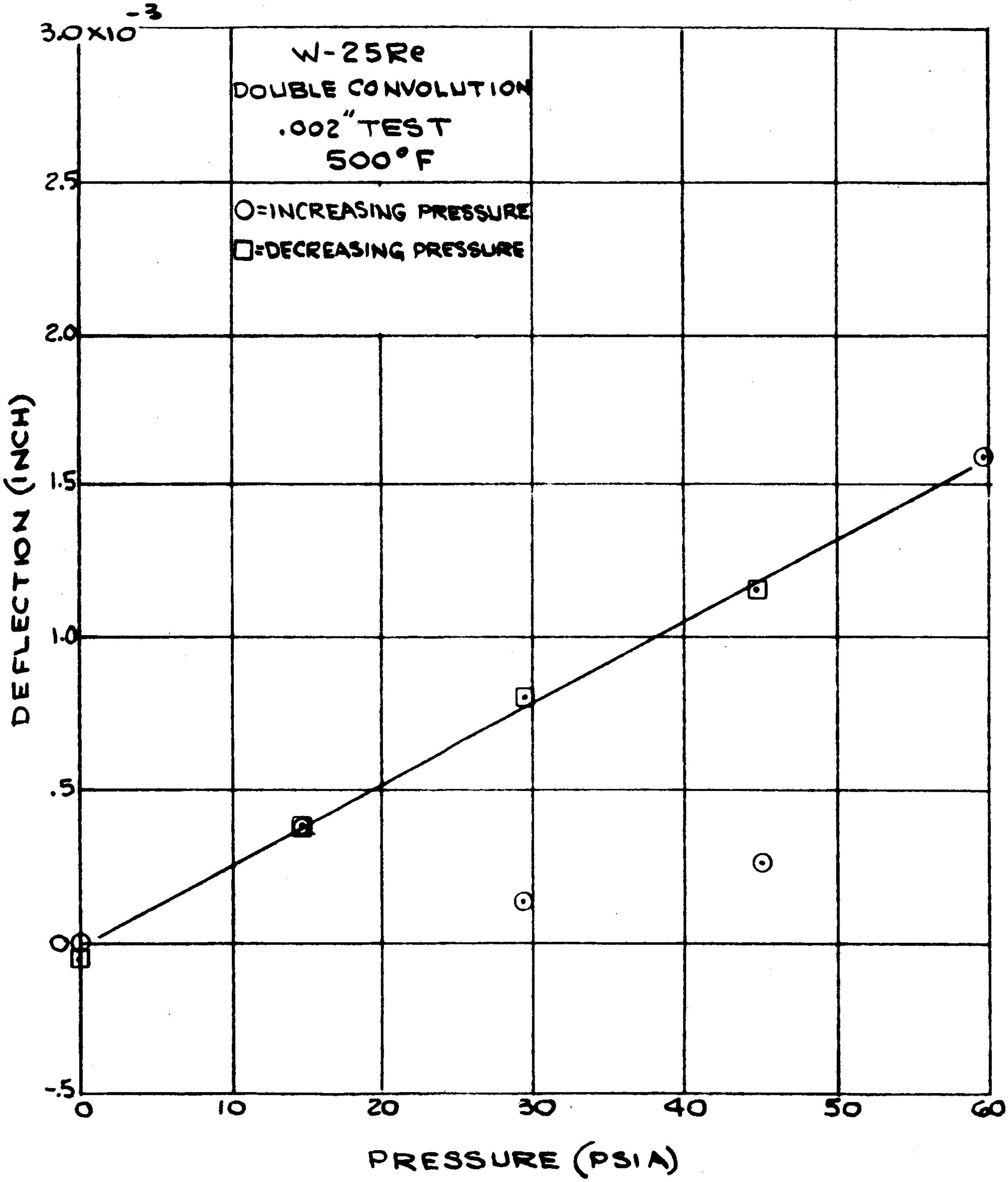

FIGURE 64

W-25Re PRESSURE-DEFLECTION, 500°F

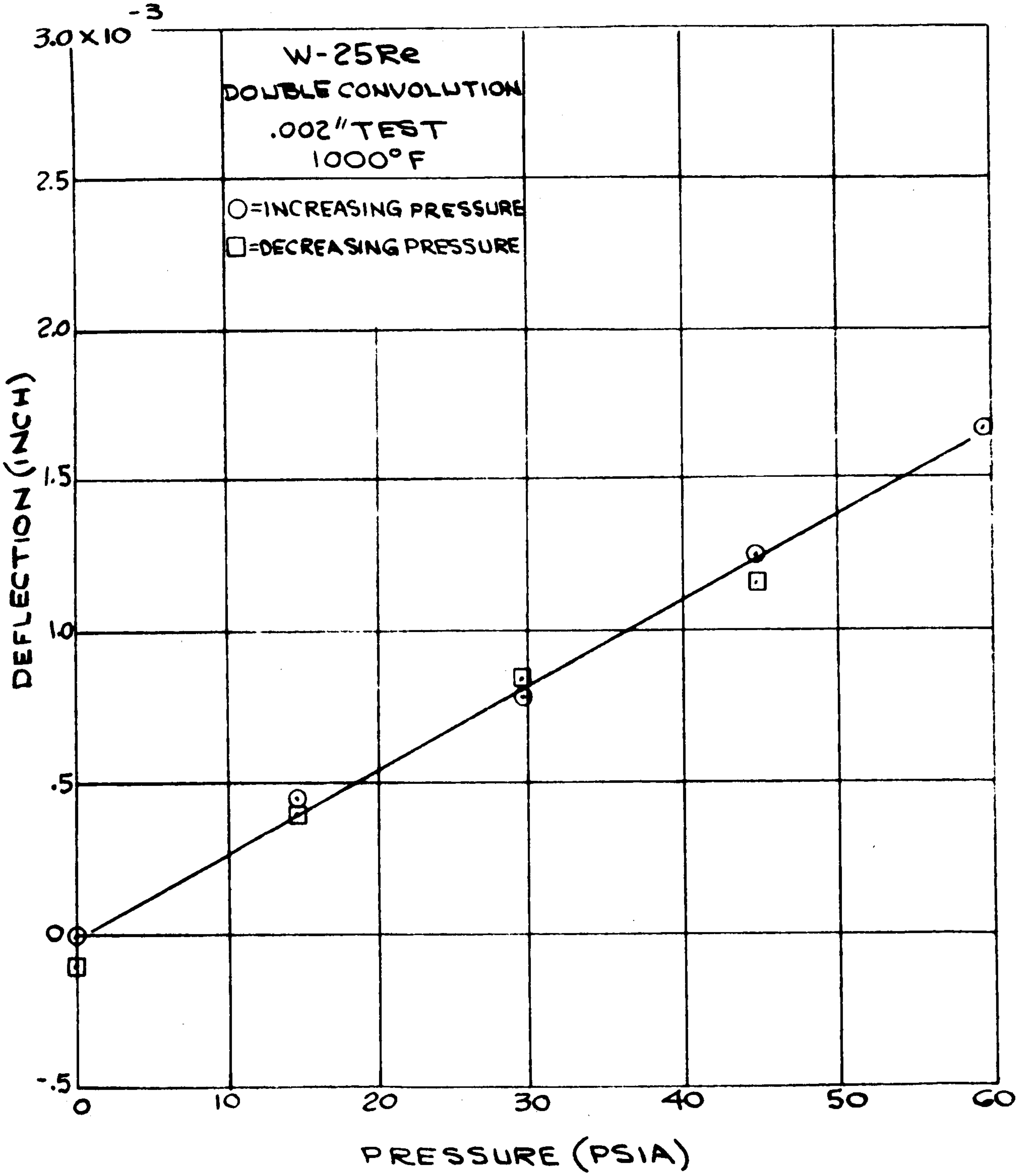

FIGURE 65

W-25Re PRESSURE-DEFLECTION, 1000°F

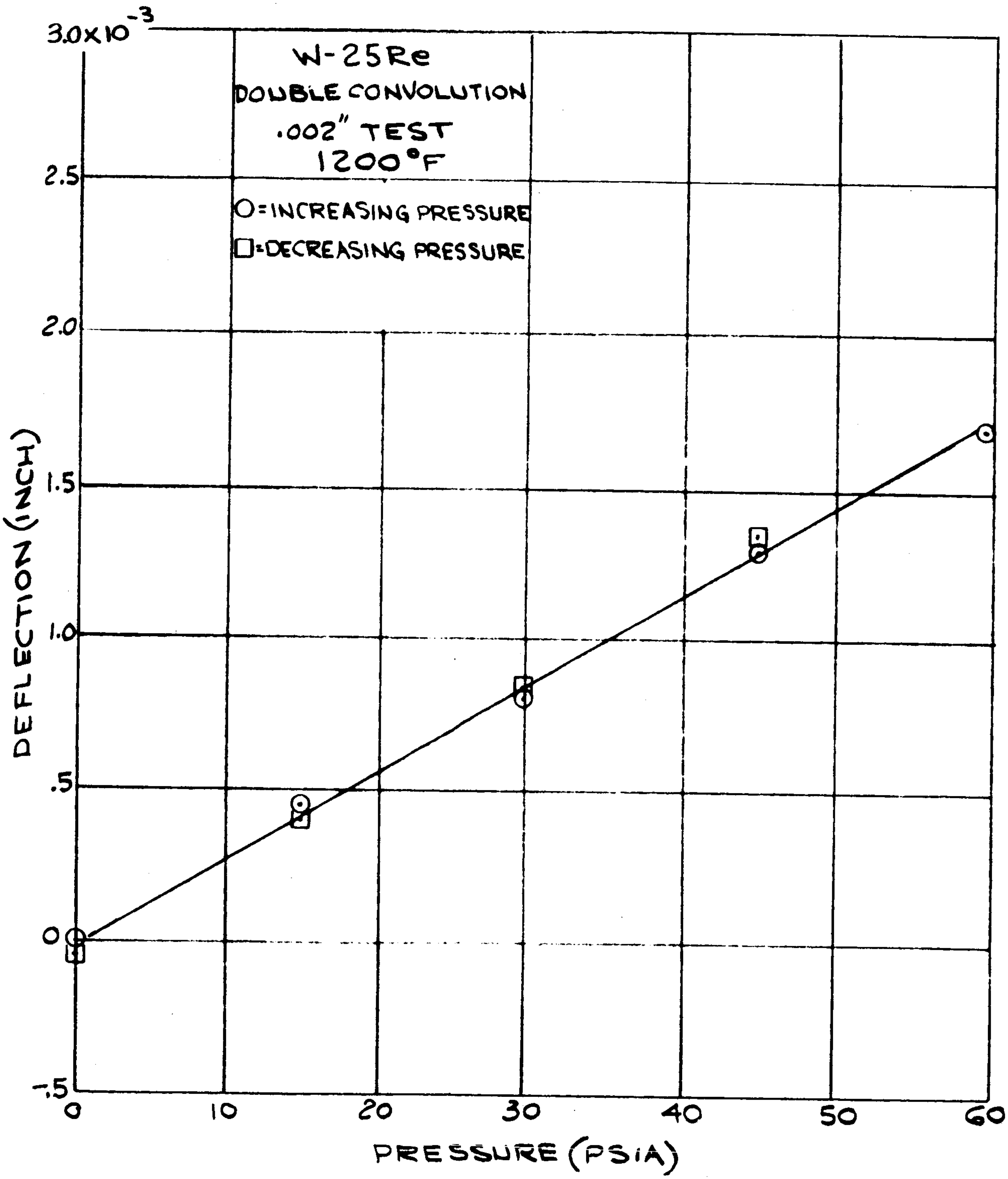

FIGURE 66

W-25Re PRESSURE-DEFLECTION, 1200°F

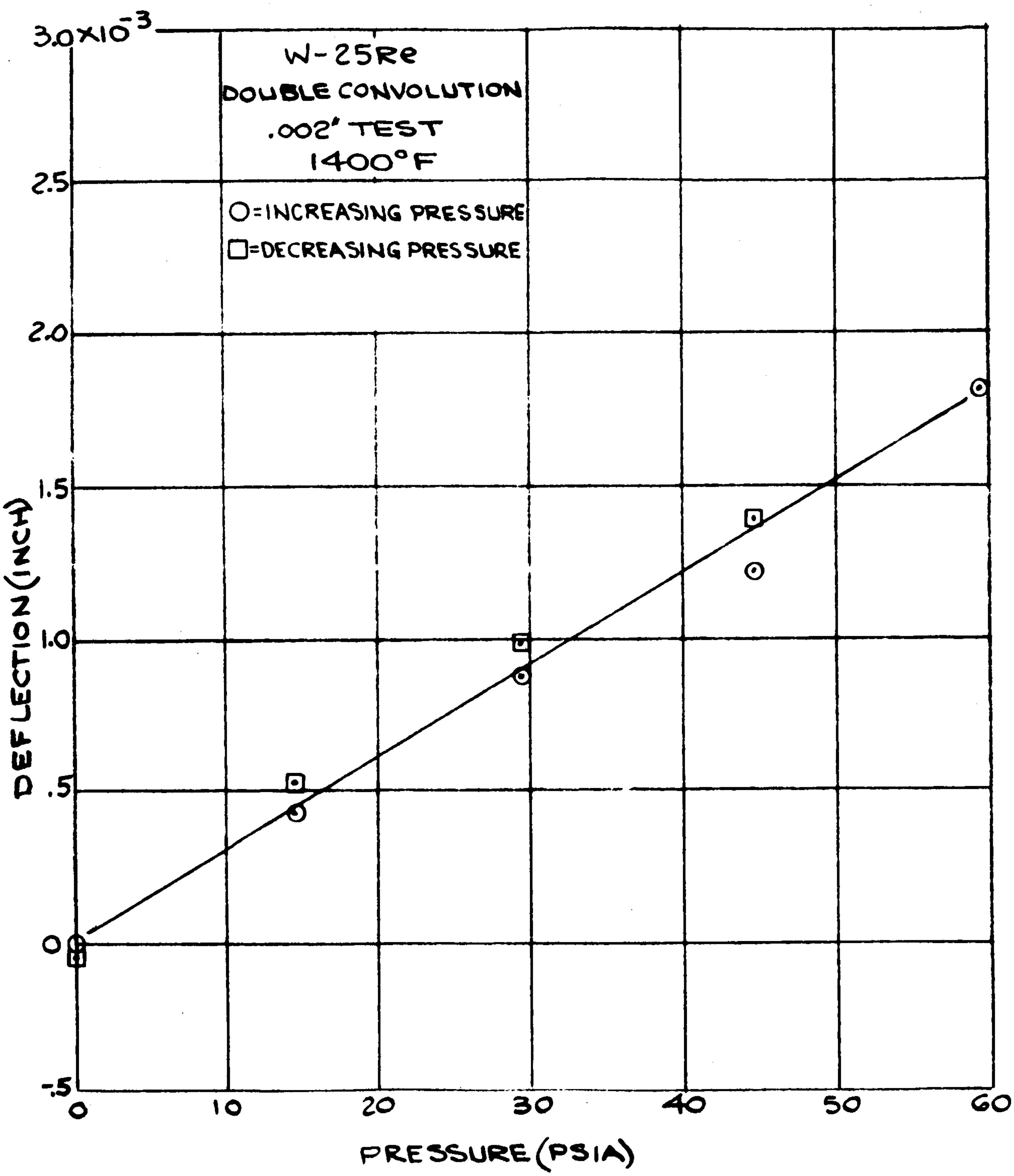

FIGURE 67

W-25Re PRESSURE-DEFLECTION, 1400°F

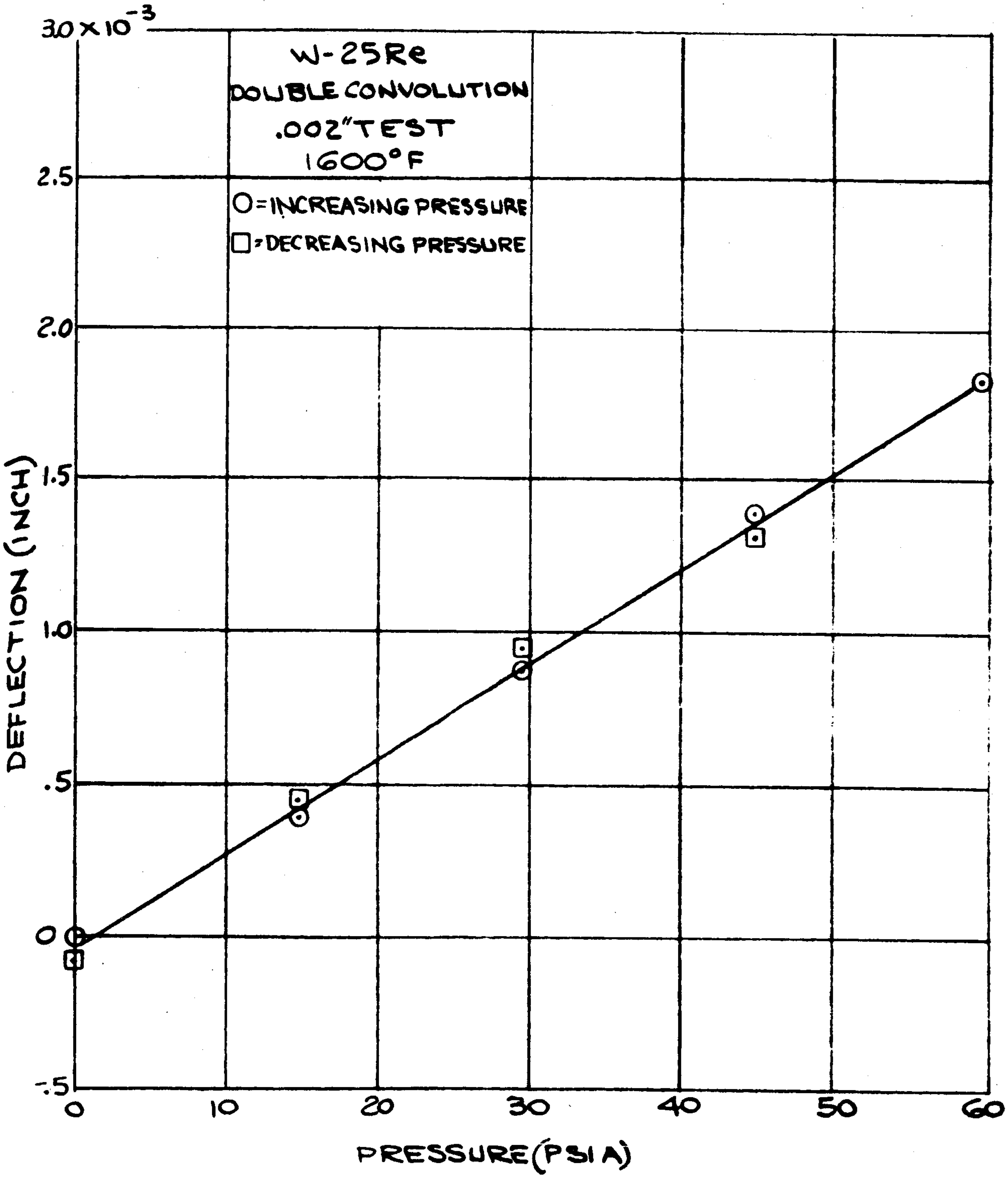

FIGURE 68

W-25Re PRESSURE-DEFLECTION, 1600°F

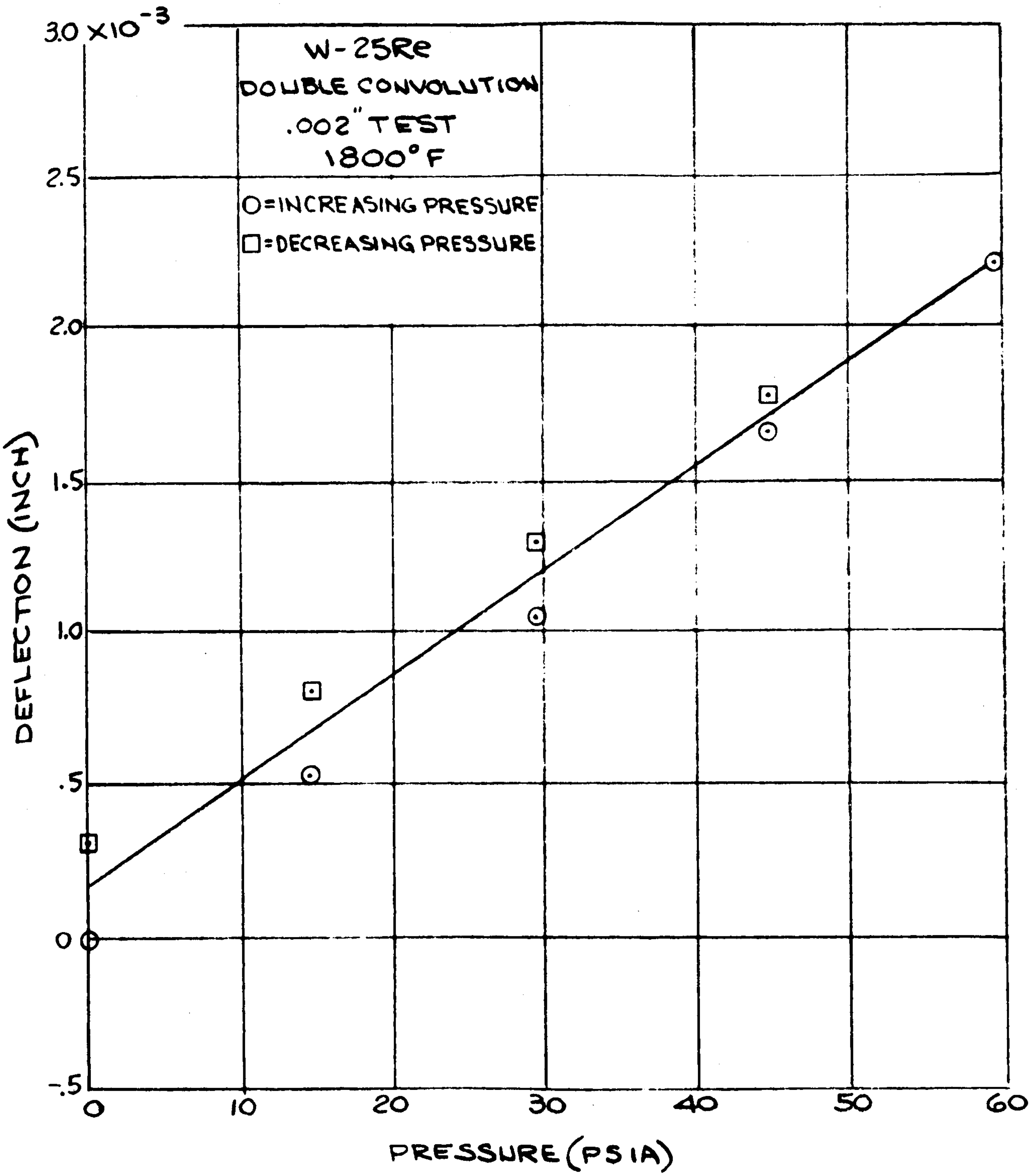

FIGURE 69

W-25Re PRESSURE-DEFLECTION, 1800°F

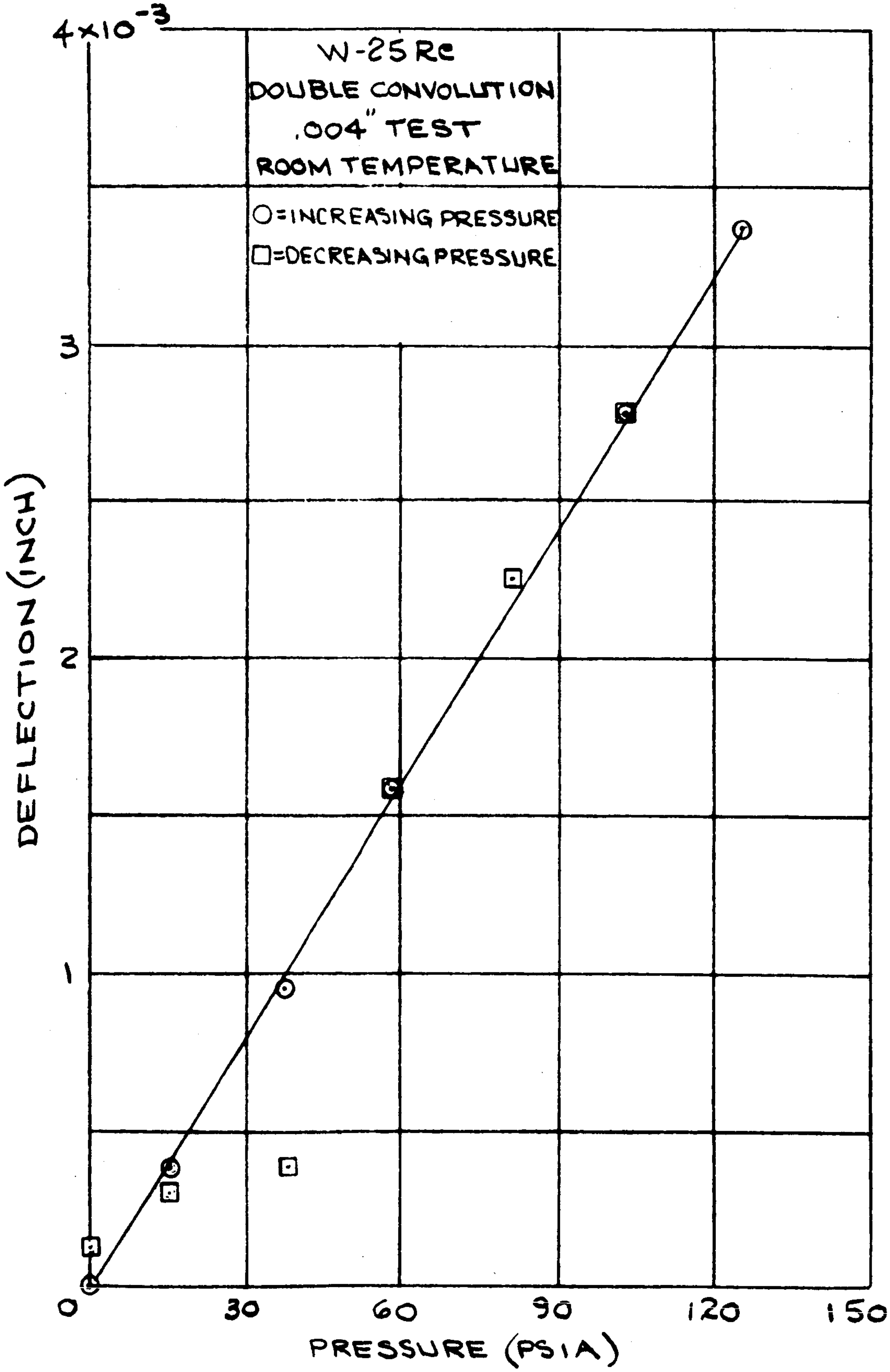

FIGURE 70

W-25Re PRESSURE-DEFLECTION, ROOM TEMPERATURE

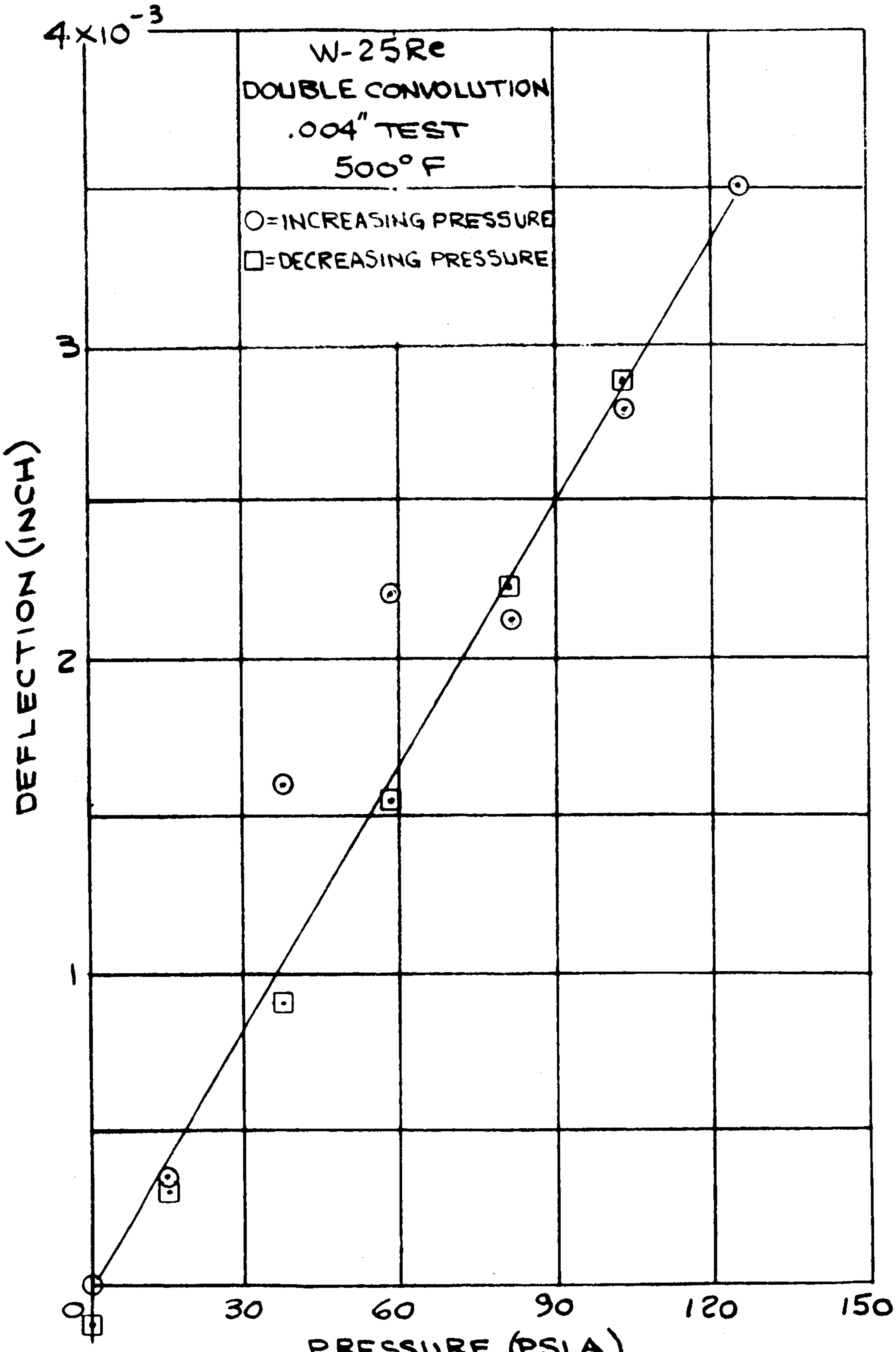

FIGURE 71

W-25Re PRESSURE-DEFLECTION, 500°F

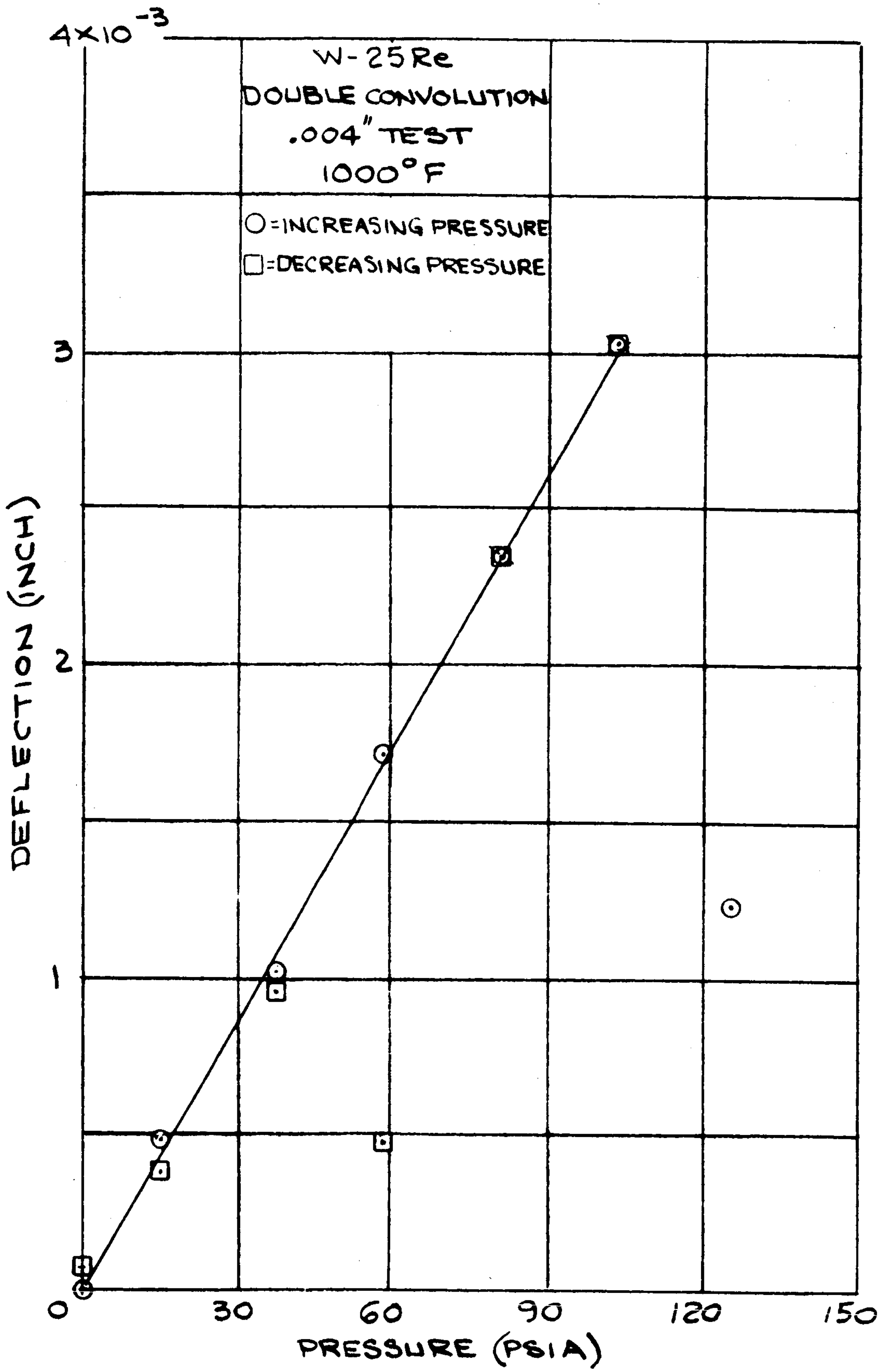

FIGURE 72

W-25Re PRESSURE-DEFLECTION, 1000°F

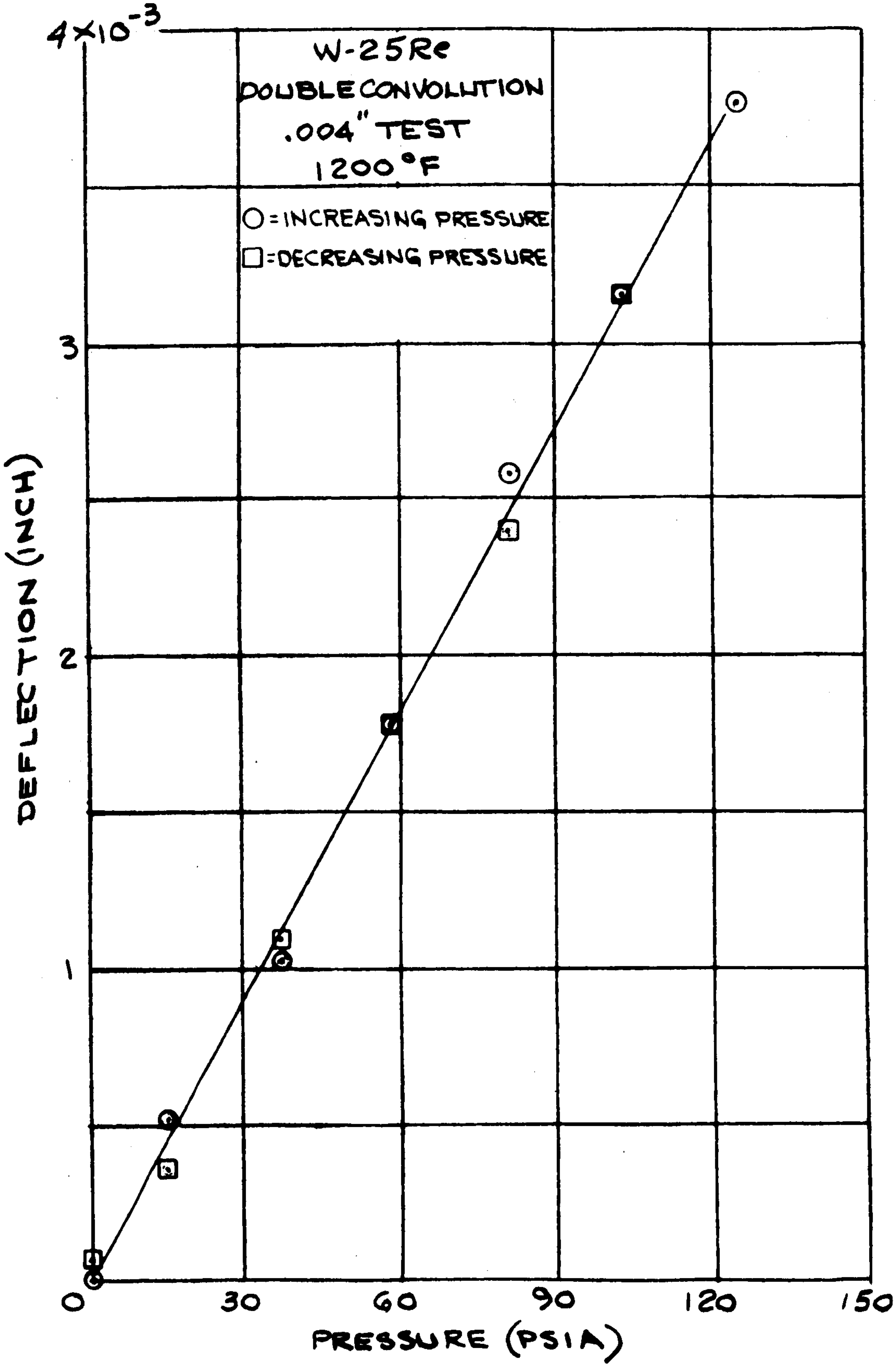

FIGURE 73

W-25Re PRESSURE-DEFLECTION, 1200°F

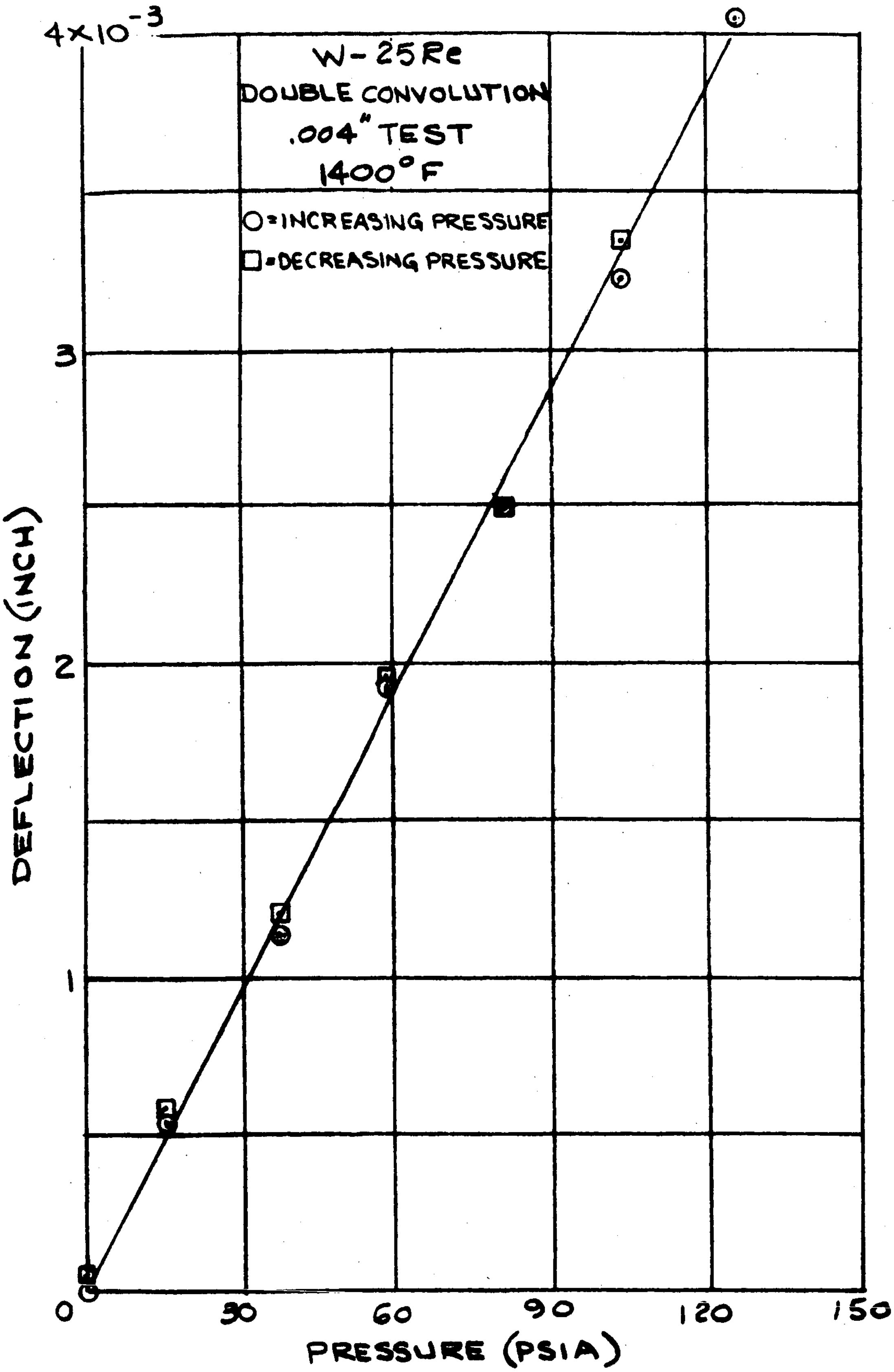

FIGURE 74

W-25Re PRESSURE-DEFLECTION, 1400°F

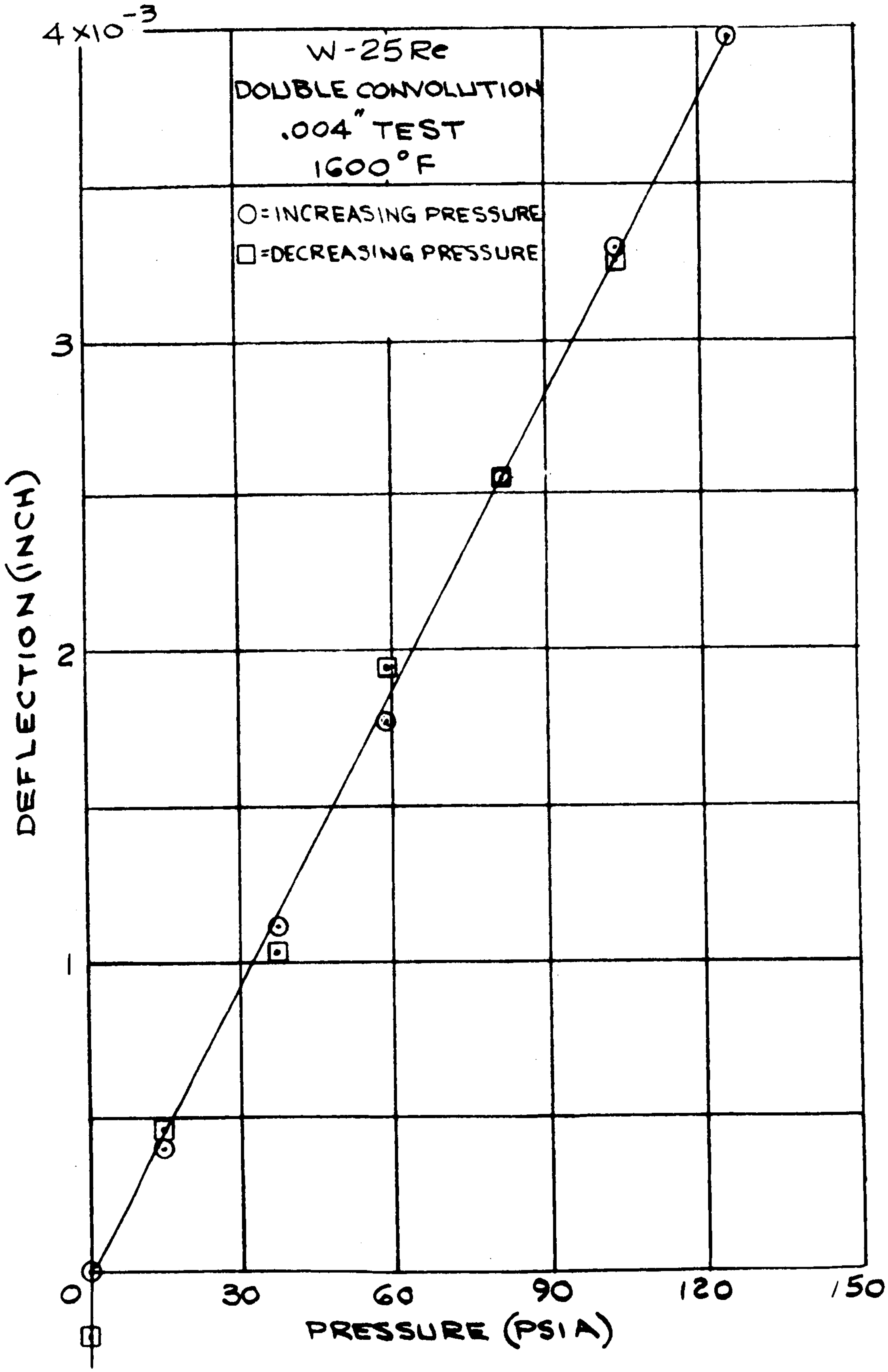

FIGURE 75

W-25Re PRESSURE-DEFLECTION, 1600°F

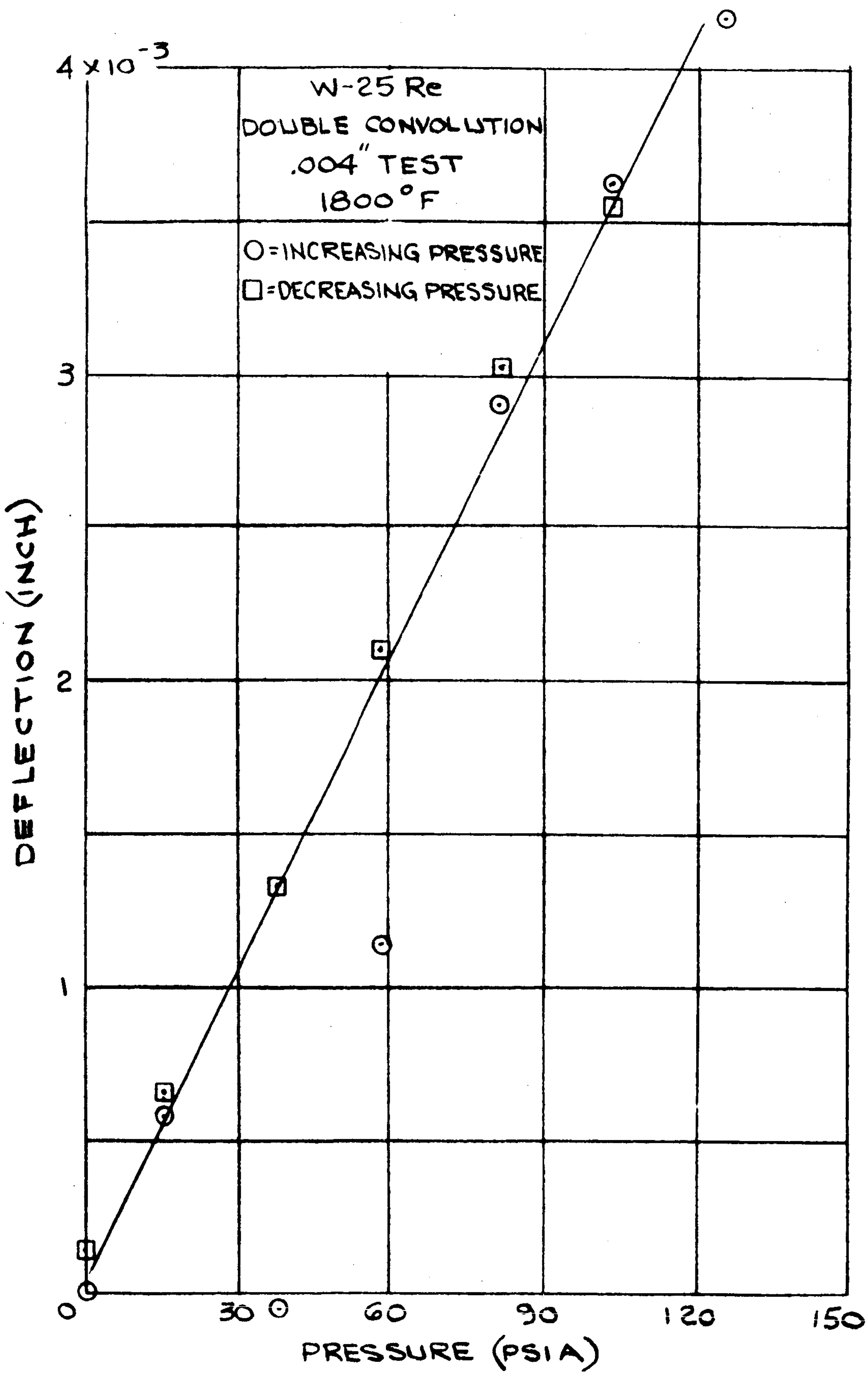

FIGURE 76

W-25Re PRESSURE-DEFLECTION, 1800°F

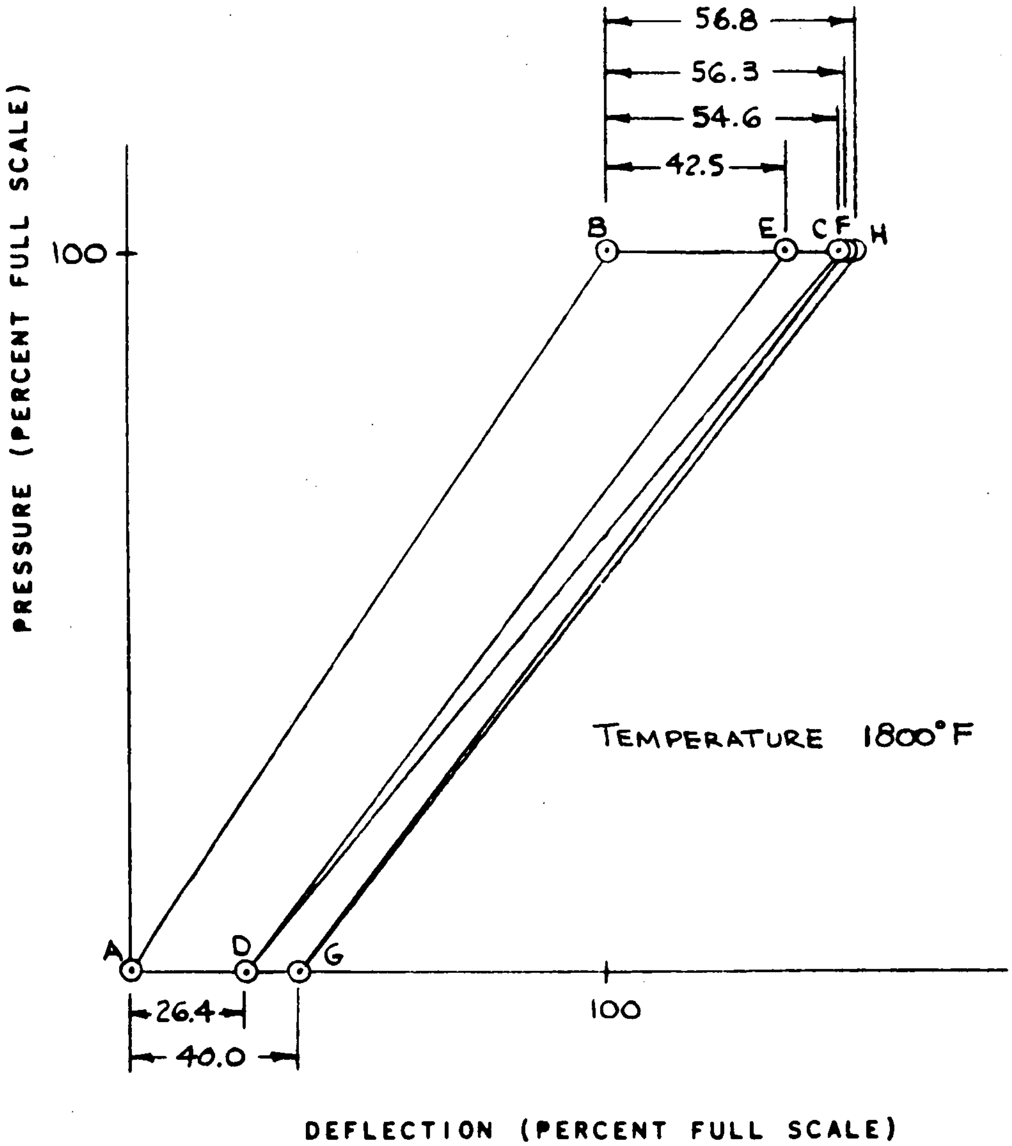

FIGURE 77

C-129Y FINAL TIME TEST PROCEDURE

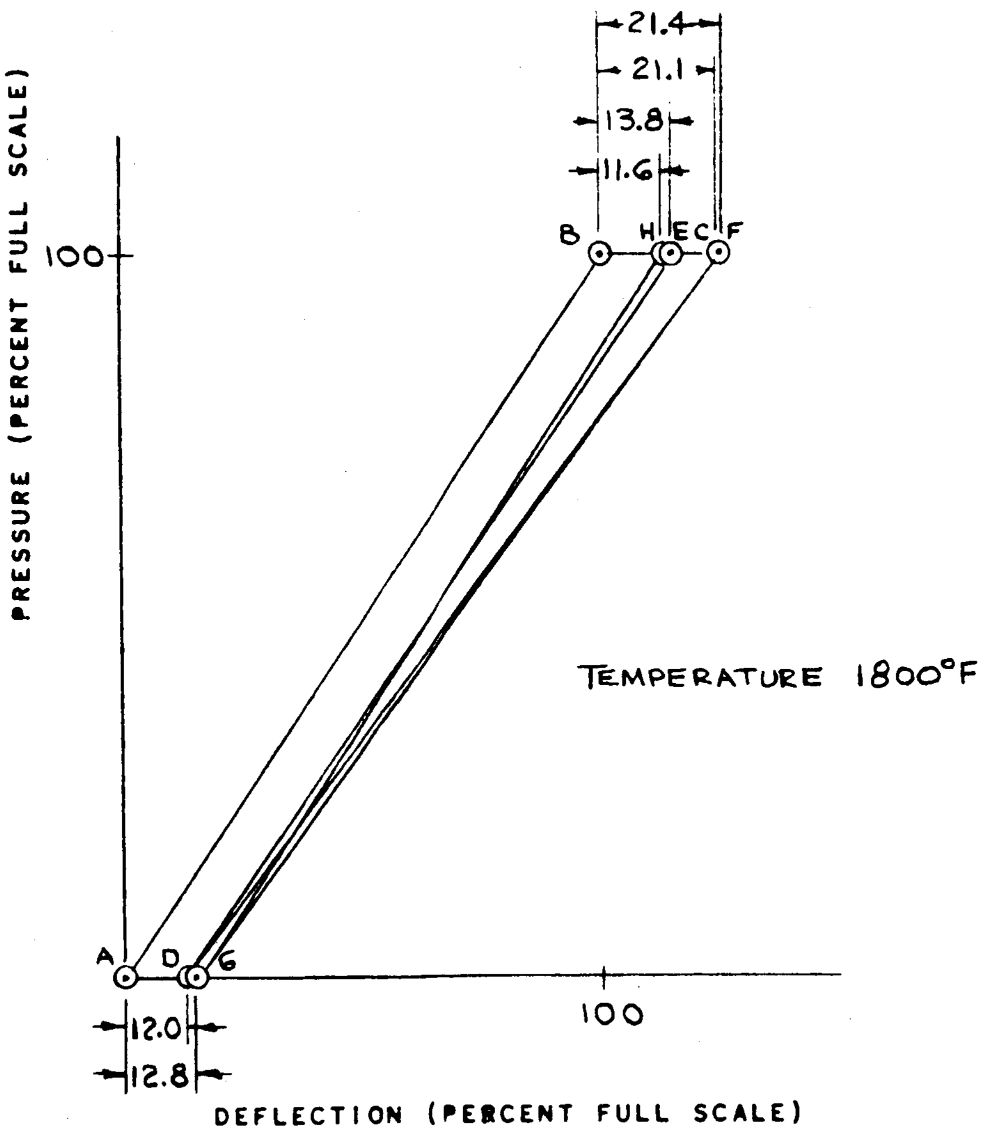

FIGURE 78

FS-85 FINAL TIME TEST PROCEDURE

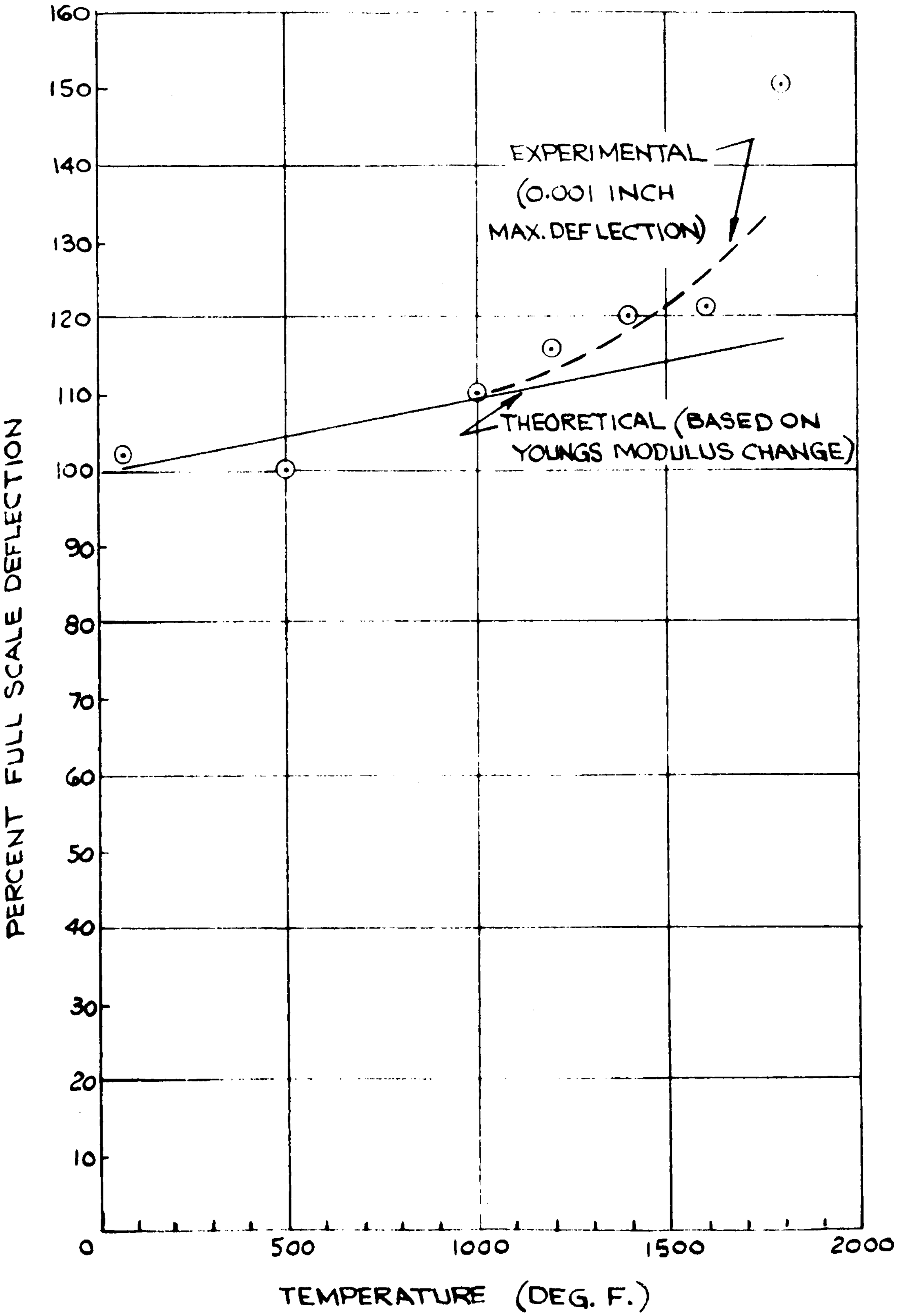

FIGURE 79

C-129Y FULL SCALE DEFLECTION-TEMPERATURE CURVES

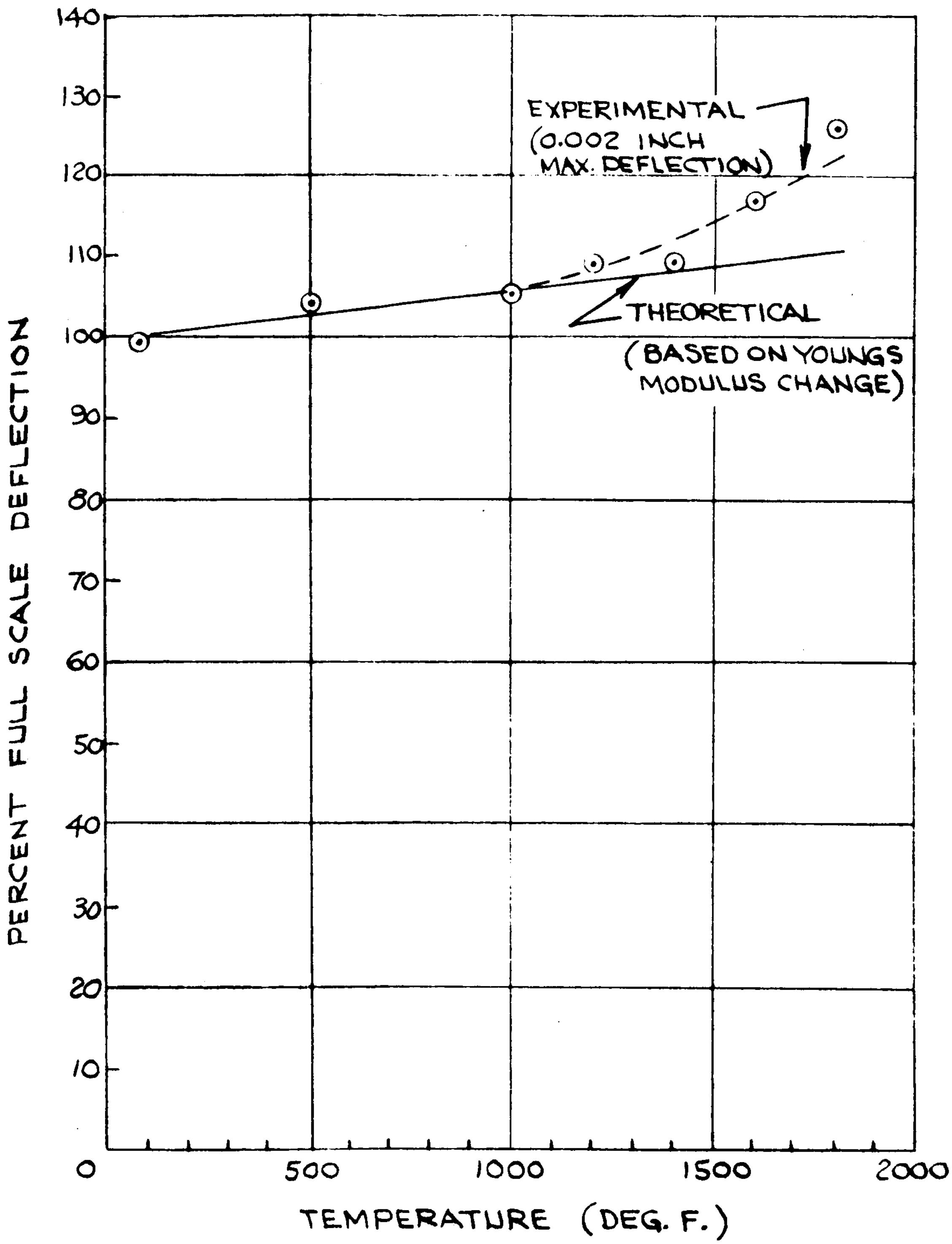

FIGURE 80

FS-85 FULL SCALE DEFLECTION-TEMPERATURE CURVES

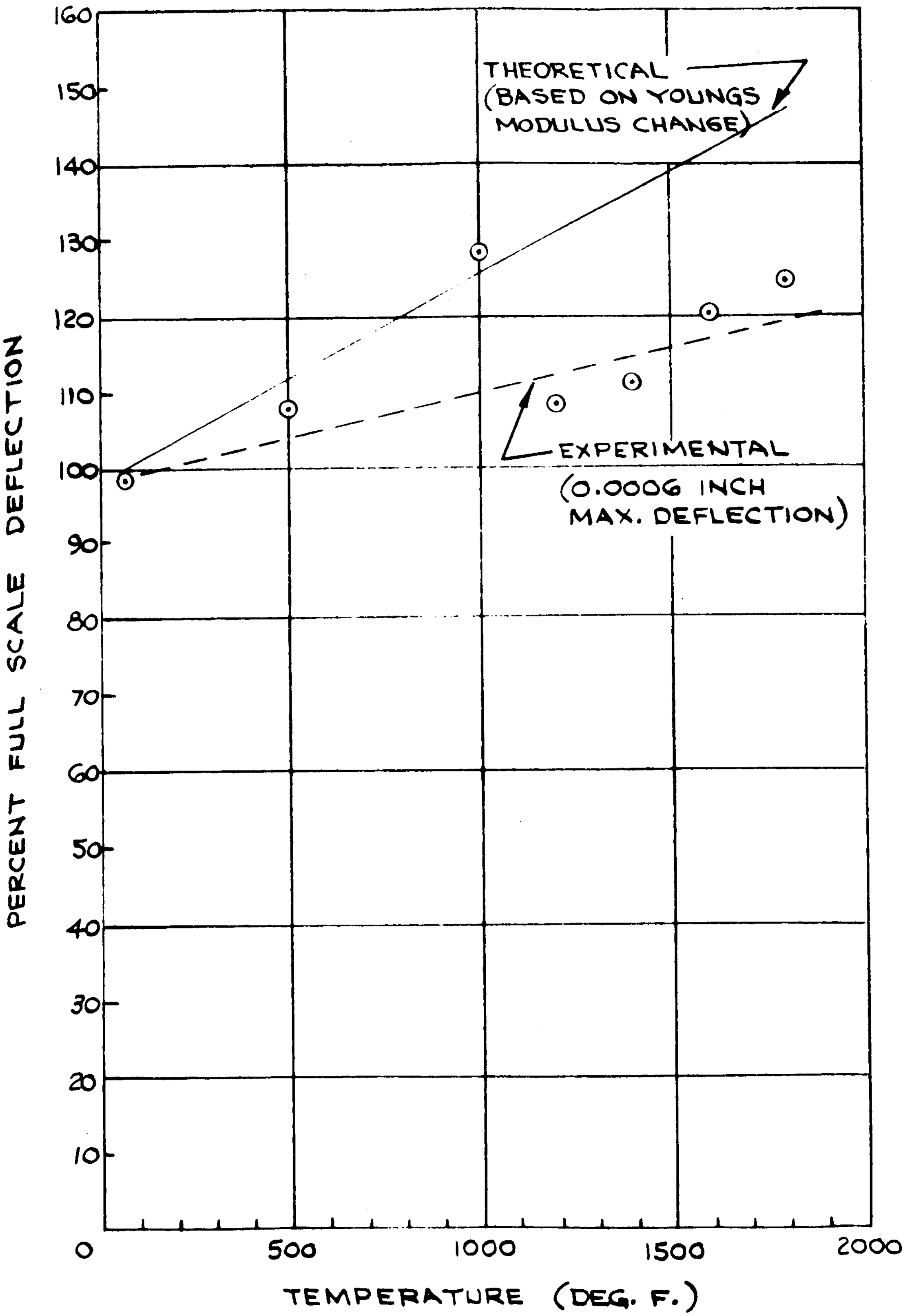

FIGURE 81

T-222 FULL SCALE DEFLECTION-TEMPERATURE CURVES

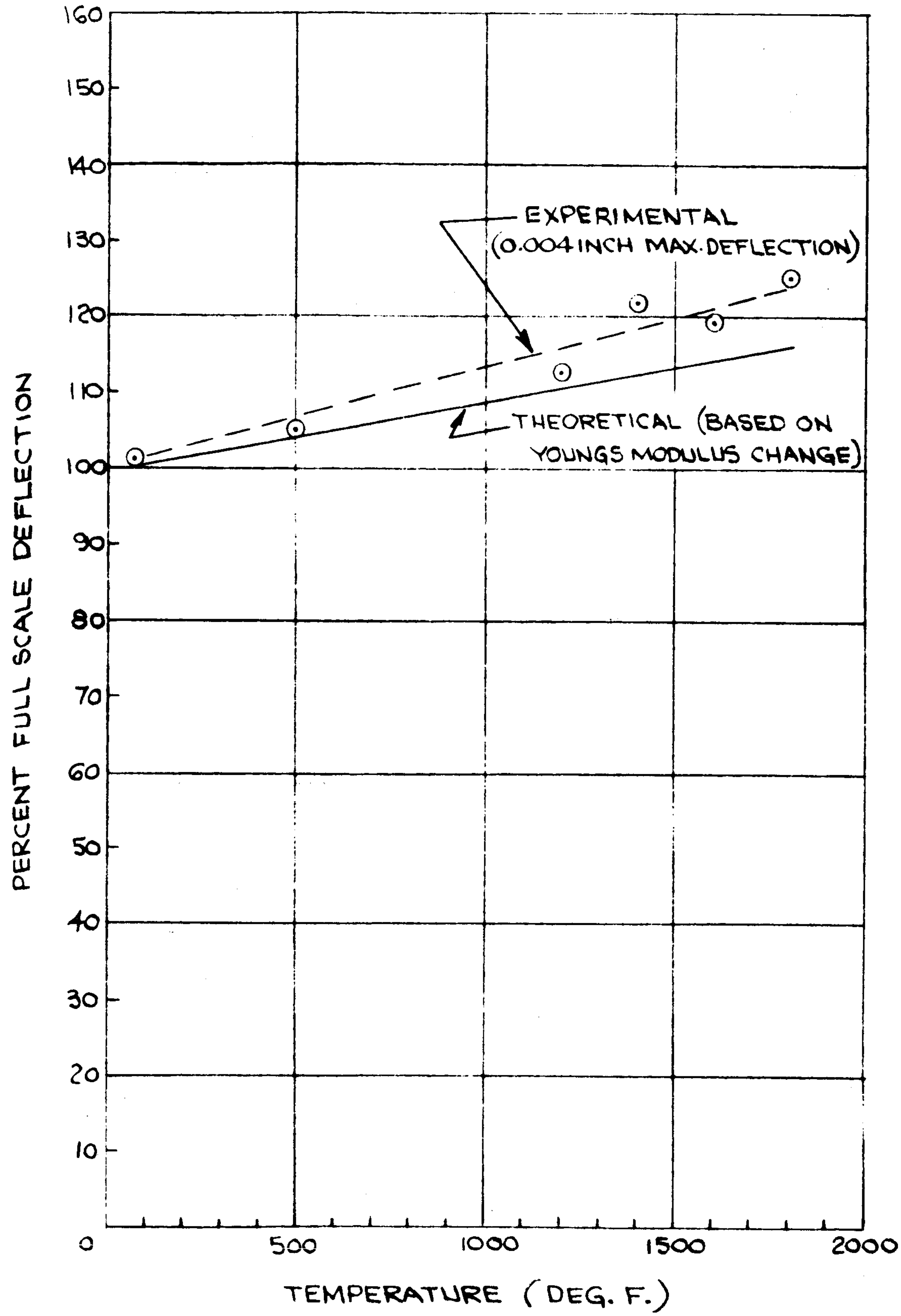

FIGURE 82

W-25Re FULL SCALE DEFLECTION-TEMPERATURE CURVES

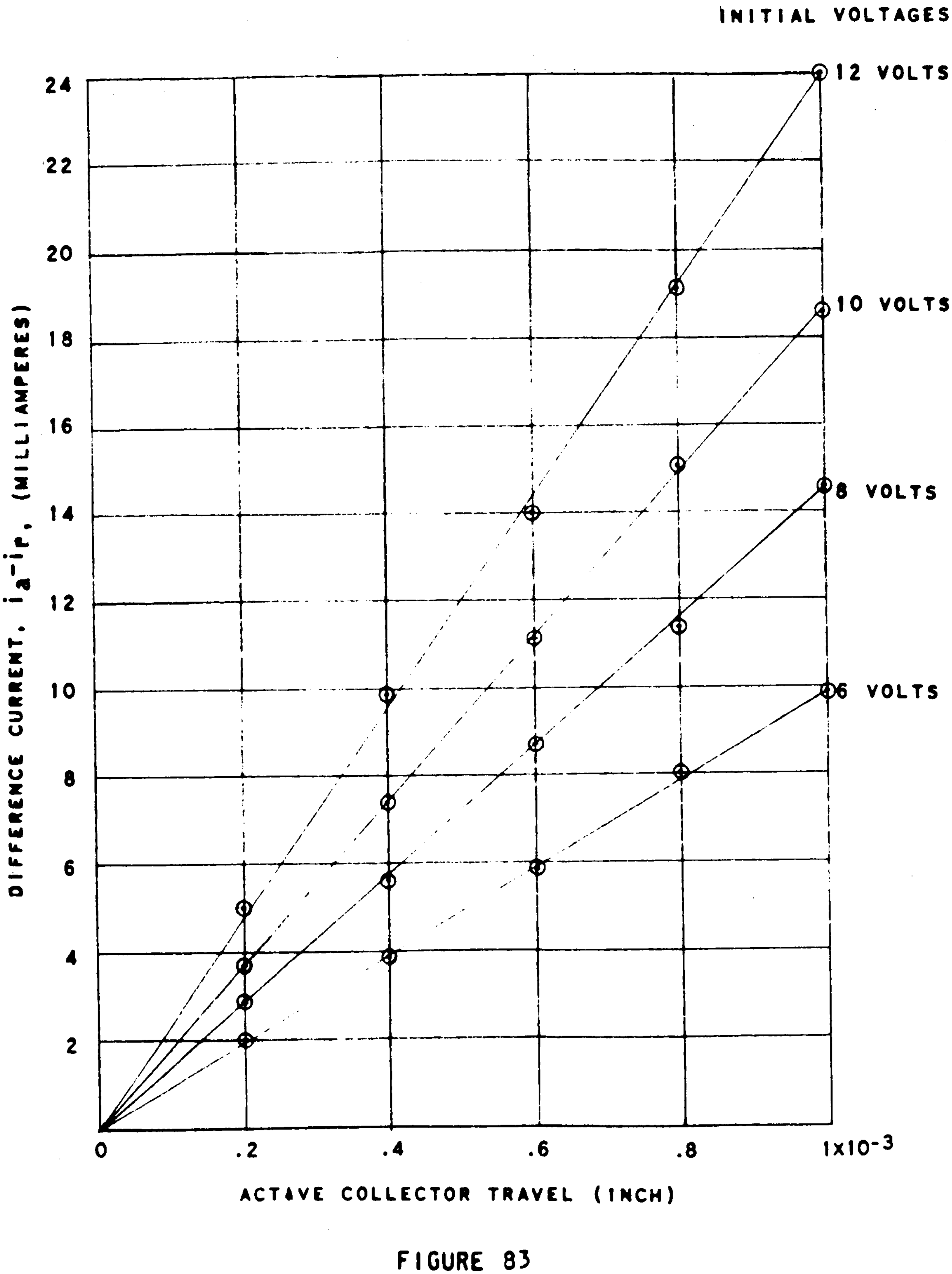

FIGURE 83

THERMIONIC DIODE SENSOR CALIBRATION

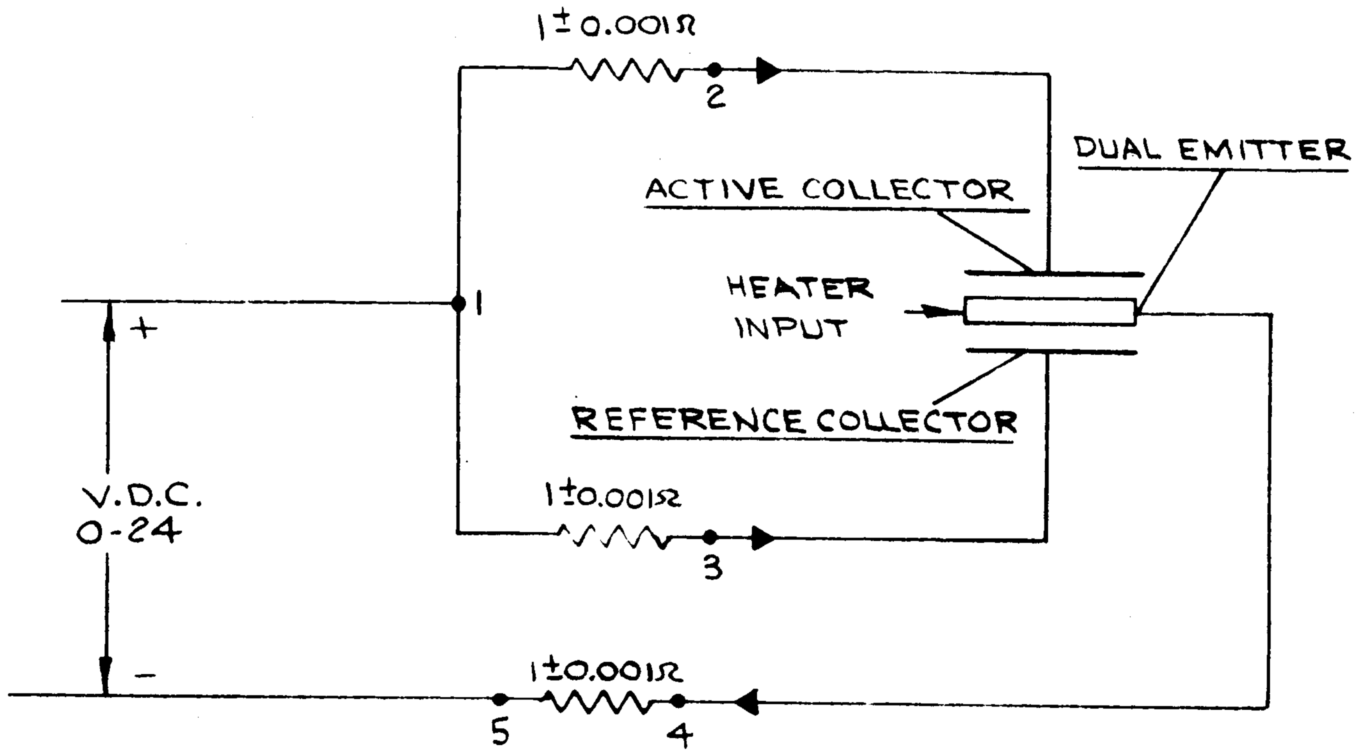

FIGURE 84

THERMIONIC TEST CIRCUITRY

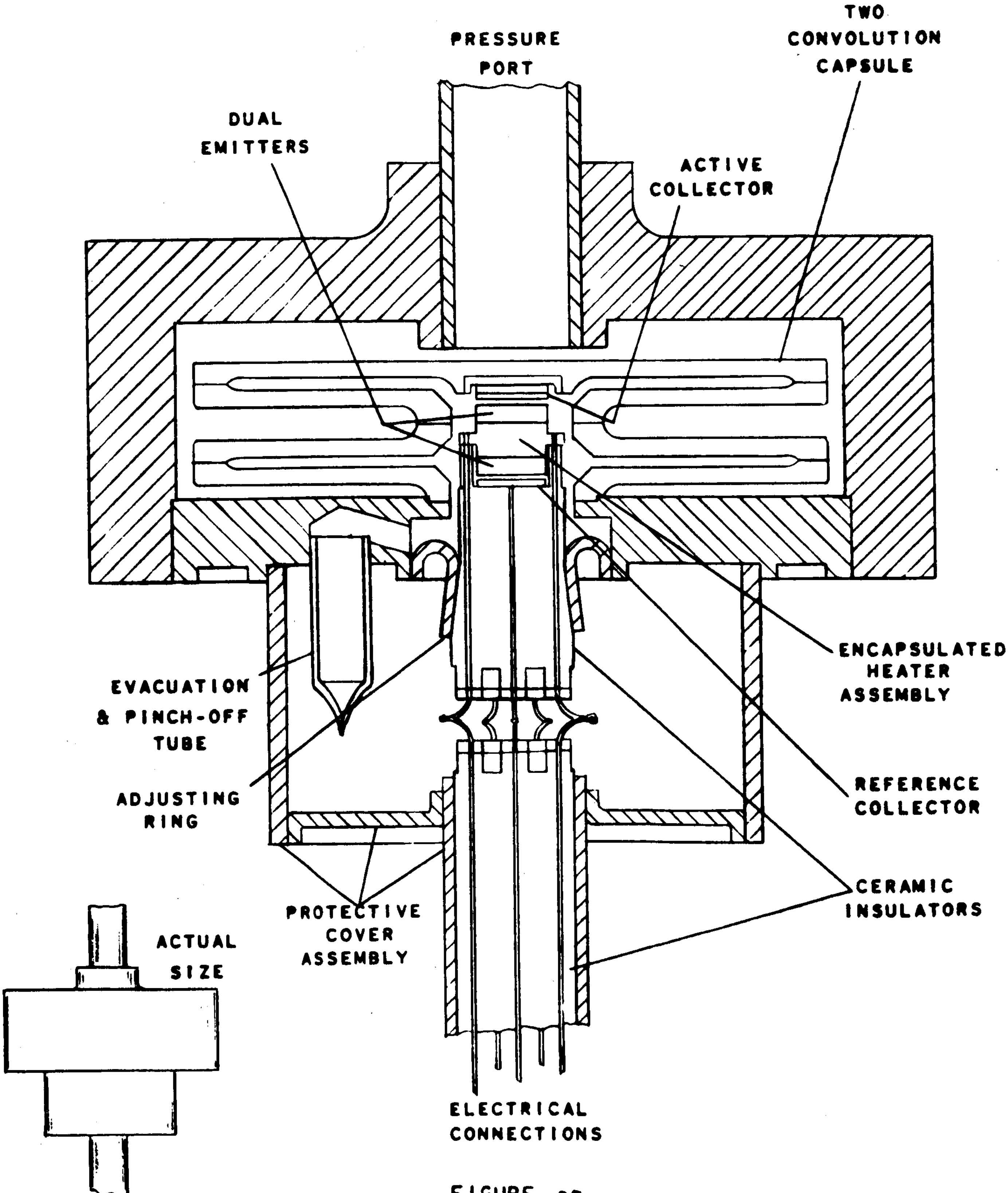

FIGURE 85

THERMIONIC PRESSURE TRANSDUCER

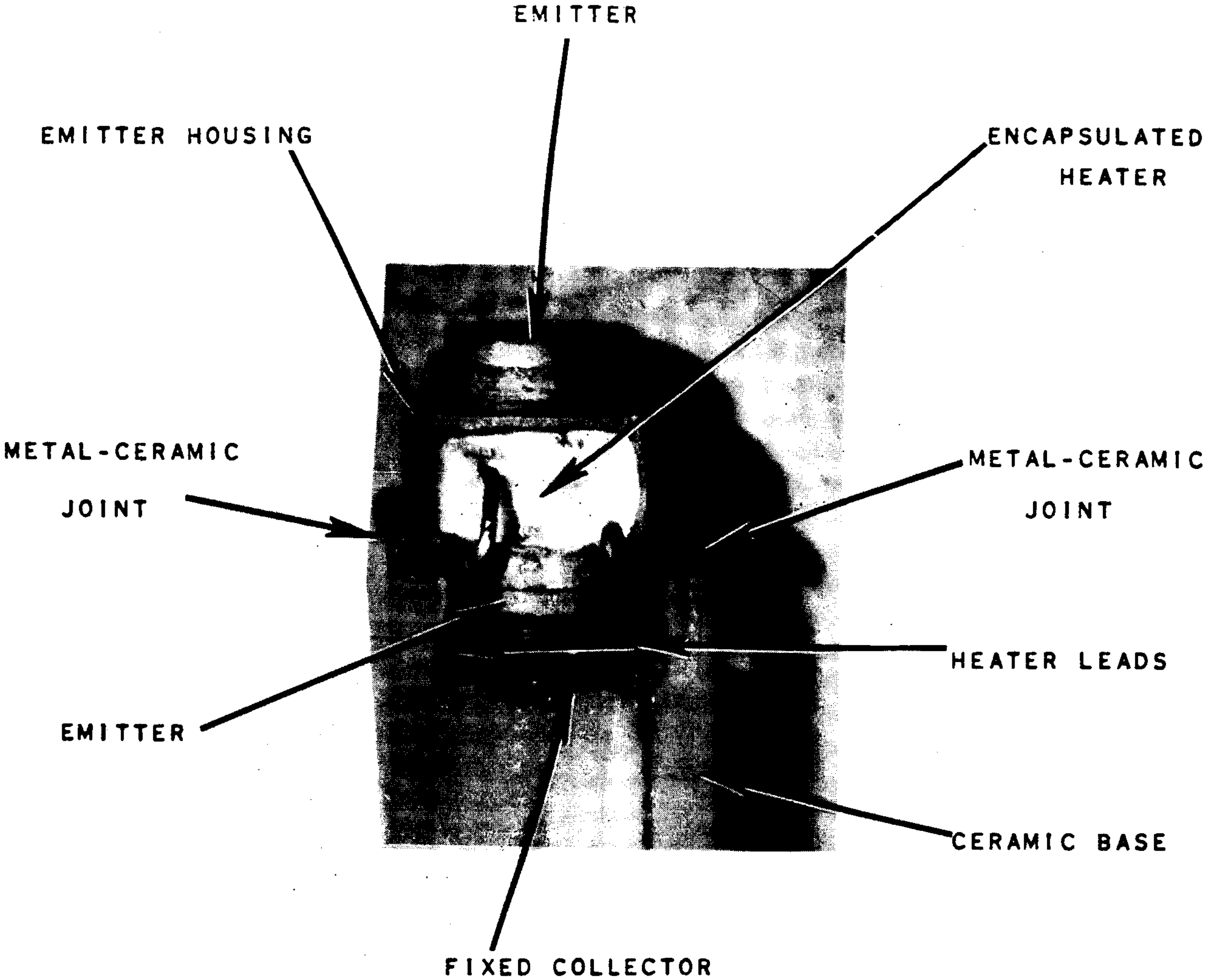

FIGURE 86

ENCAPSULATED HEATER-CERAMIC BASE ASSEMBLY

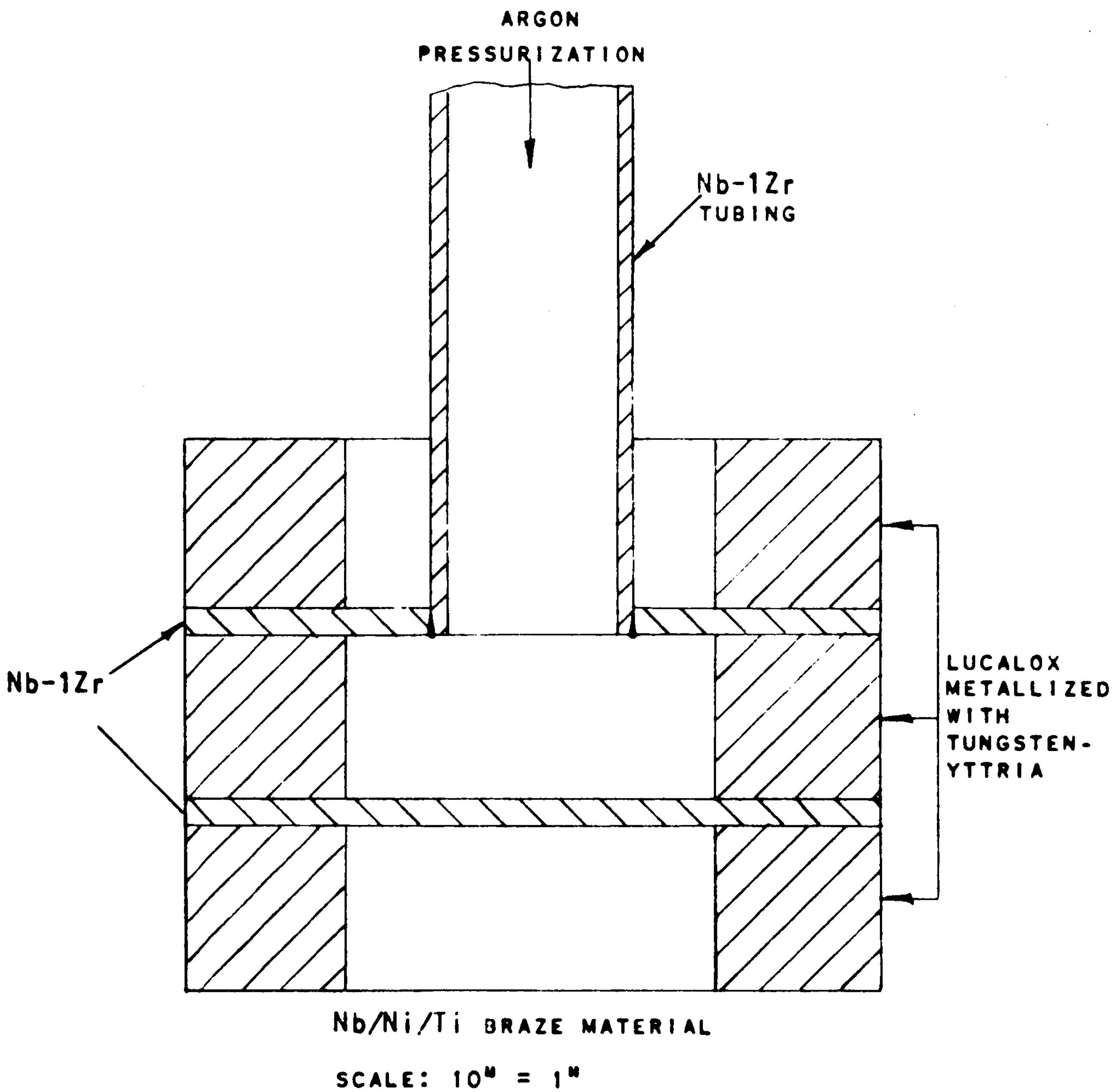

FIGURE 87

METAL-CERAMIC TEST UNIT

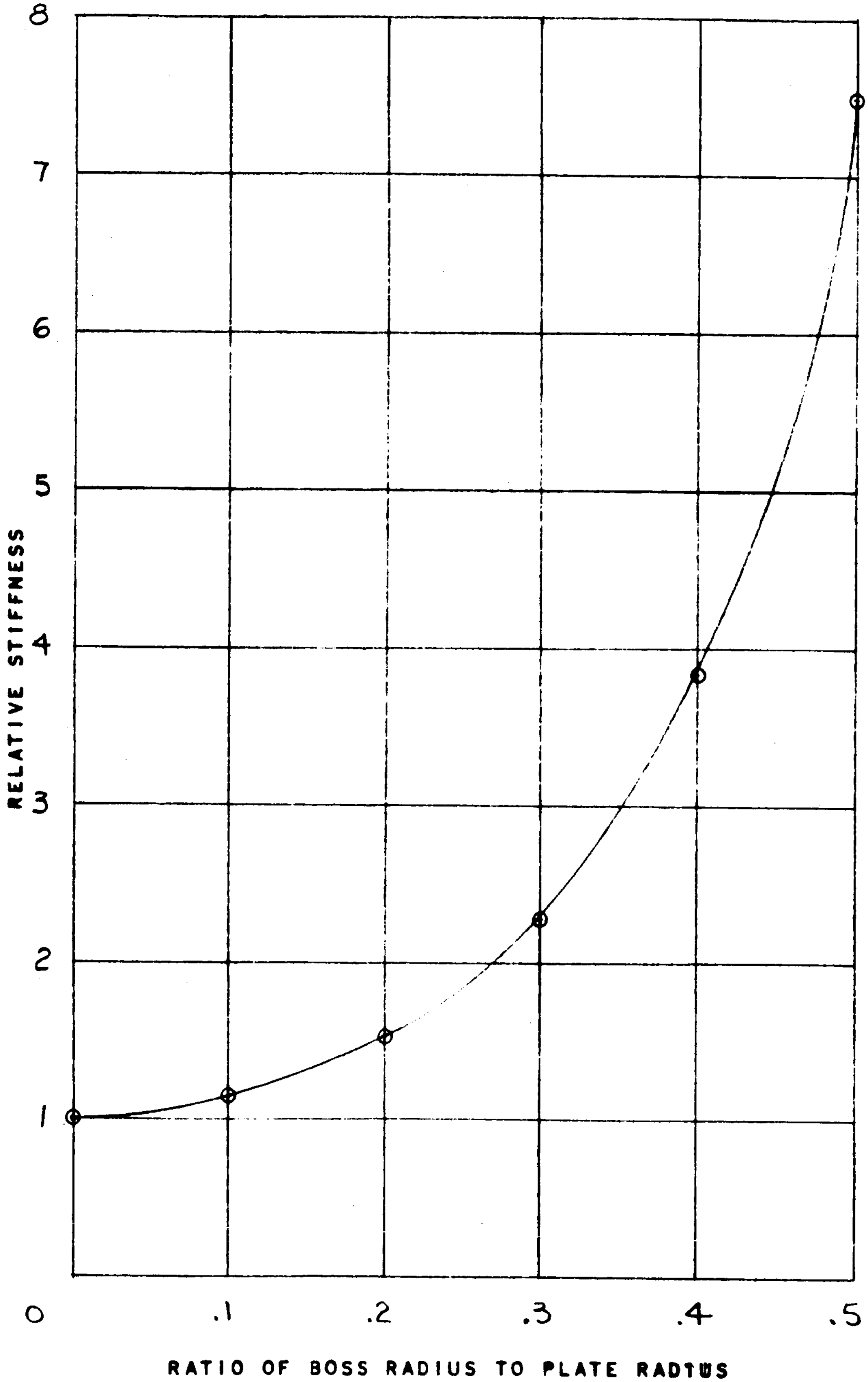

FIGURE 88

RELATIVE STIFFNESS OF DIAPHRAGM WITH CENTRAL BOSS

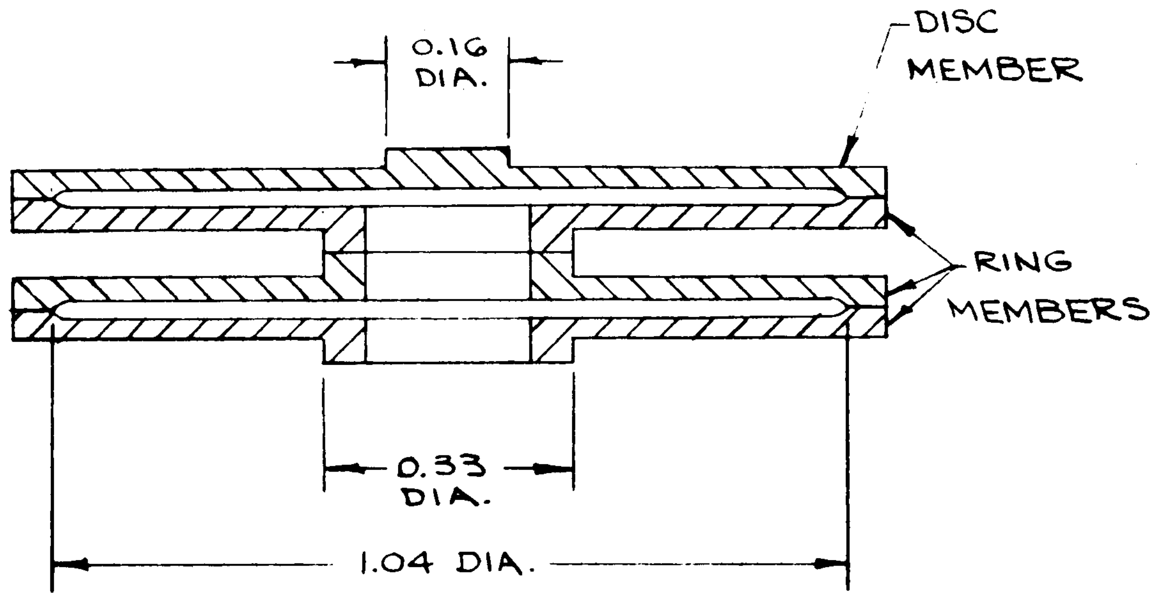

FIGURE 8.9

RING/DISC MACHINED DIAPHRAGM CAPSULE

LIST OF REFERENCES

1. R. E. Engdahl, "First Quarterly Report, Pressure Measuring Systems for Closed Cycle Liquid Metal Facilities", NASA CR-54140, July 2, 1964.

2. R. E. Engdahl, "Second Quarterly Report, Pressure Measuring Systems for Closed Cycle Liquid Metal Facilities", NASA CR-54193, September 28, 1964

3. A. J. Cassano, "Third Quarterly Report, Pressure Measuring Systems for Closed Cycle Liquid Metal Facilities", NASA CR-54276, December 28, 1964.

4. R. J. Roark, "Formulas for Stress and Strain", Third Edition, McGraw-Hill, 1954, p. 200.

APPENDIX A

NOMENCLATURE

a	Radius of diaphragm
b	Radius of boss
E	Modulus of elasticity
i_a	Thermionic active collector current
i_r	Thermionic reference collector current
m	Reciprocal of Poisson's ratio
t	Thickness of diaphragm
w	Applied load on diaphragm
y	Deflection of diaphragm

APPENDIX B

EQUIVALENCE BETWEEN SINGLE AND DOUBLE CONVOLUTION CAPSULES

Roark (Reference 4) presents the following expression for the maximum deflection of a flat plate diaphragm with a central boss. The outer edge is fixed and supported and there is a uniform load over the entire actual surface.

$$y = \frac{3w(m^2-1)}{16m^2Et^3}\left[a^4 + 3b^4 - 4a^2b^2 - 4a^2b^2 \ln\frac{a}{b} + \frac{16a^2b^4}{a^2-b^2}\left(\ln\frac{a}{b}\right)^2\right] \qquad \text{(B1)}$$

where y = maximum deflection of plate (inch)

w = uniform applied load (psi)

m = reciprocal of Poisson's ratio

E = modulus of elasticity

t = thickness of plate (inch)

a = radius of plate (inch)

b = radius of central boss (inch)

If the relative stiffness of a diaphragm is defined as the ratio of the deflection of the diaphragm without a boss (b = o) to the deflection of the diaphragm with a boss, application of Equation B1 results in the data presented in Figure 88. The relative stiffness is plotted as a function of the ratio of the boss radius to the plate radius (b/a). The bigger the boss relative to the disk diameter, the greater the relative stiffness.

Applying this analysis to the ring/disc machined diaphragm capsule as used in this program the relative stiffness of the ring member (a = 1.04 inch, b = 0.33 inch) is 2.48; the relative stiffness of the disc member (a = 1.04 inch, b = 0.16 inch) is 1.30. Therefore, for a given applied force, the disc will deflect 2.48/1.30 = 1.91 times as much as the ring member. (See Figure 89.)

The deflections of the single convolution (1 ring, 1 disc) and double convolution (3 rings, 1 disc) capsules may be compared by normalizing the ring deflection to a value of 1.0. The disc deflection is therefore 1.91.

The total normalized deflection for the single convolution capsule is

$$1\ (1.0) + 1\ (1.91) = 2.91$$

The total normalized deflection for the double convolution capsule is

$$3\ (1.0) + 1\ (1.91) = 4.91$$

The relative deflection of the single convolution capsule to the double convolution capsule is

$$2.91/4.91 = 0.593 \approx 0.6$$

Therefore, a 0.001 inch maximum deflection test on a double convolution capsule is equivalent to testing a single convolution capsule at 0.0006 inch maximum deflection.

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